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CONSULTANT REPORT ON EMISSIONS AND FUEL-ECONOMY TEST METHODS AND PROCEDURES

Richard A. Matula

National Research Council

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September 1974

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EMISSIONS AND FUEL-ECONOMY TEST METHODS AND PROCEDURES

CONSULTANT REPORT TO THE:
Committee on Motor Vehicle Emissions
Commission on Sociotechnical Systems

SEPTEMBER 1974

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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CONSULTANT REPORT

to the

Committee on Motor Vehicle Emissions

Commission on Sociotechnical Systems

National Research Council

on

EMISSIONS AND FUEL-ECONOMY TEST METHODS AND PROCEDURES

PREPARED BY:

Richard A. Matula

Washington, D.C.

September 1974

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NOTICE

This consultant report was prepared by a consultant at the request of the Committee on Motor Vehicle Emissions of the National Academy of Sciences. Any opinions or conclusions in this consultant report are those of the consultant and do not necessarily reflect those of the Committee or of the National Academy of Sciences.

This consultant report has not gone through the Academy review procedure. It has been reviewed by the Committee on Motor Vehicle Emissions only for its suitability as a partial basis for the report by the Committee.

The findings of the Committee on Motor Vehicle Emissions, based in part upon material in this consultant report but not solely dependent upon it, are found only in the Report by the Committee on Motor Vehicle Emissions of November 1974.

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PREFACE

The National Academy of Sciences, through its Committee on Motor Vehicle Emissions (CMVE), initiated a study of automobile emissions-control technologies at the request of the United States Congress and the Environmental Protection Agency (EPA) in October 1973. To help carry out its work, the CMVE engaged panels of consultants to collect information and to prepare consultant reports on various facets of motor vehicle emissions control. This Consultant Report on Emissions and Fuel-Economy Test Methods and Procedures is one of five consultant reports prepared and submitted to the Committee in connection with the Report by the Committee on Motor Vehicle Emissions of November 1974. The other consultant reports are:

An Evaluation of Catalytic Converters for Control of Automobile Exhaust Pollutants, September 1974

Emissions Control of Engine Systems, September 1974

Field Performance of Emissions-Controlled Automobiles, November 1974

Manufacturability and Costs of Proposed Low-Emissions Automotive Engine Systems, November 1974

These five consultant reports are NOT reports of the National Academy of Sciences or its Committee on Motor Vehicle Emissions. They have been developed for the purpose of providing a partial basis for the report by the Committee as described more fully in the cover NOTICE.

The reader should note that most of the data referred to in this consultant report were obtained prior to August 1974.

Acknowledgment

The author would like to extend his sincere thanks to Mr. David Milks of the Combustion Kinetics Laboratory, Drexel University, for his significant contributions in data collection, interpretation and analysis which were essential elements in the development of this consultant report.

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1.0 SUMMARY AND CONCLUSIONS

1.1 SUMMARY

In order to evaluate the technological feasibility of meeting the automotive emission standards, with particular emphasis upon systems and engines for meeting various levels of NO_x emissions and upon the question of fuel economy, the Committee on Motor Vehicle Emissions (CMVE) of the National Academy of Sciences required information relating to the reliability and reproducibility of emissions and fuel economy measurements. Since the reliability and reproducibility of any experimental measurement is defined by the test methods and procedures utilized to obtain the measurement, the important aspects of present and projected emission and fuel economy test methods and procedures for light-duty motor vehicles (LDMV) have been considered.

The CVS-CH exhaust-emission test procedure plays an important role in the certification process for 1975 and subsequent model-year LDMV. Hence, the statistical variability of CVS-CH emission tests for these vehicles and the relative magnitudes of the various factors affecting both systematic and random errors encountered during CVS-CH tests are considered. Additional questions concerning the effect of ambient temperature on exhaust emissions, the suitability of present exhaust-emission-control durability test methods and procedures and the possible modifications of the present HC exhaust-emission standards and measuring techniques designed to account for only reactive HC are also addressed. Finally, recent data relating to the effectiveness of present evaporative HC emission test methods and procedures and LDMV evaporative-control systems are presented and discussed.

At the present time, generally accepted standardized fuel economy test methods and procedures are not available. Due to the significance of this issue, it is important that standardized test methods and procedures, based on sound engineering and scientific considerations, be developed as soon as possible. In the general area of fuel economy, the important factors affecting LDMV fuel economy, the important elements in any standardized fuel economy test method and procedure, the currently proposed test methods and procedures and the statistical variability of fuel economy measurements are discussed.

1.2 CONCLUSIONS

A. Evaporative hydrocarbon emissions, based on tests employing the SHED test procedure, from vehicles equipped with present technology-control systems have been shown to be higher than 1975-76 Federal hydrocarbon-exhaust standards when both are compared on a grams-per-mile basis. Evaporative-emission tests, based on the method presently specified in the 1975 FTP on similar vehicles, have indicated that evaporative-hydrocarbon emissions are considerably lower than the 1975-76 exhaust standards. These conflicting results indicate that an accurate test method and procedure for measuring evaporative-HC emissions must be developed and implemented.

B. The driving cycle associated with the CVS-CH test presents an average urban trip "as well as it needs to" for the purposes of determining light-duty motor vehicle-exhaust emissions.

C. Significant consequences should not be attached to a single CVS-CH exhaust-emission test.

D. Significant systematic errors in mean emission values of a given test vehicle have been reported between various emission-testing laboratories. Routine mandatory exhaust-emission-correlation-test programs between laboratories could significantly reduce these systematic errors.

E. Variations in barometric pressure and fluctuations in test-cell temperature and humidity, within the ranges specified in the CVS-CH test method, have been shown to significantly affect measured exhaust emissions. Hence, the establishment of close tolerances on the ambient test-cell temperature and humidity for the CVS-CH test method and the development of correction factors relating barometric pressure and exhaust emissions would reduce statistical variations in CVS-CH exhaust-emission-test results.

F. Ambient temperature variations, commonly encountered in large sections of the nation during winter, can significantly increase exhaust emissions of HC and CO above the emissions measured during the course of the CVS-CH test.

G. Statistical variability associated with the evaluation of deterioration factors, often obtained from tests on a single durability-data car, may reflect the special circumstances of the test rather than the capability of the underlying technology. An averaging procedure over a larger group of similar vehicles might be preferable. However, a too-extensive use of averaging treats all vehicles and systems as equal and, hence, attractive technologies are counterbalanced by less desirable technologies.

H. In order to obtain a reasonably accurate determination of the fuel economy of a vehicle, two fuel economies, one designed to represent urban driving and one designed to represent highway driving, are needed to provide rational consumer choice.

I. It has been shown that severe fuel economy penalties are incurred when a light-duty motor vehicle is driven on a short trip that is initiated from a cold-start condition. Since a significant number of urban trips are very short and initiated from a cold start, an urban fuel economy driving cycle should include a cold-start phase.

J. The CVS-CH driving cycle is a sufficiently accurate representation of urban driving patterns to be used as the urban fuel economy driving cycle.

K. Either the Carbon-Mass-Balance Method or the direct measurement of the mass or volume of fuel consumed can be employed to obtain accurate (less than 5%) measurements of fuel consumption.

L. There is no inherent technical reason for eliminating the use of chassis dynamometers in fuel economy testing.

M. Definitive studies designed to evaluate the ability of chassis dynamometers to accurately simulate vehicular fuel economy for a variety of driving cycles have not been reported.

N. Fuel economy tests incorporating chassis dynamometers can be successfully employed to determine fuel economies for urban driving cycles.

O. Certain vehicles may obtain higher fuel economies than are actually warranted on the EPA highway cycle using present EPA fuel economy test methods and the dynamometer loads specified in the Federal Register.

P. Reported fuel economies should be based on the results of several tests even though these tests are relatively reproducible.

2.0 INTRODUCTION

2.1 Purpose and Panel Organization

The National Academy of Sciences (NAS), through its Committee on Motor Vehicle Emissions (CMVE), initiated a study of automobile emission-control technologies at the request of the United States Congress and the Environmental Protection Agency (EPA) in October 1973. Particular emphasis in this study was to be placed upon systems and engines that can meet various levels of NO_x emissions and upon the question of fuel economy. In order to assess the feasibility of meeting emission standards and the relative merits of present and alternate automotive technologies, CMVE required information relating to the reliability and reproducibility of emissions and fuel economy measurements.

The Emissions and Fuel Economy Test Methods and Procedures Consultant Panel, established by CMVE, was organized in January 1974. The charge to the Panel was to assess present and projected test methods and procedures pertaining to both regulated emissions and fuel economy of light-duty motor vehicles (LDMV).

Panel members made site visits to most domestic automobile manufacturers, various state and federal agencies and a number of other organizations concerned with automotive emissions and fuel economy testing to gather data from which to draw conclusions. Information from nondomestic automobile manufacturers was collected at a meeting in Washington at which many such companies were represented. A number of foreign organizations concerned with testing were also site-visited. In addition, data were collected from the open literature, material presented at technical meetings and from various professionals. Appendix A lists the organizations visited or interviewed, and Appendix B contains a typical questionnaire that was sent to most organizations prior to the visit.

2.2 Scope

The reliability and reproducibility of any experimental measurement is defined by the test methods and procedures utilized to obtain the measurement. This fact is particularly applicable to the measurement of emissions and fuel ecnomy, since the tests in a test cell or on a test track attempt to measure quantities that only really exist as the composite averages taken over a large group of similar vehicles being driven by all drivers on all streets and roads. An ideal set of test methods and procedures would duplicate these real-life conditions and determine the average emissions and fuel economy for a group of vehicles. This ideal is impossible to attain in a test cell or test track and, hence, it is necessary to carefully define tests which provide reasonable approximations to the real-life values. A logical examination should show that the tests yield results whose reliability, reproducibility and cost are commensurate with the primary goals of controlling air pollution and evaluating the relative fuel economics of various vehicles. This logical examination must include an evaluation of how closely the tests duplicate real-life conditions, the reproducibility of the results and whether viable alternatives give significantly better results.

In order to address these questions, this consultant report is organized into four main sections dealing with: Vehicle Use Patterns and Driving Cycles; Emission Test Methods and Procedures; Fuel Economy Test Methods and Procedures; and, Evaluation of the Data. Vehicle use patterns and driving cycles are discussed first since it has been established that both emissions and fuel economy are dependent upon the driving cycle.

The CVS-CH exhaust-emission test procedure plays an important role in the certification process for LDMV and, hence, the statistical variability of the exhaust-emission test for 1975 and subsequent model-year vehicles is considered in Section 4.0. The relative magnitudes of the various factors affecting both systematic and random errors encountered during CVS-CH tests are considered, and potential changes in the test method designed to improve the statistical reproducibility of exhaust-emission tests are discussed. Other important factors such as the effect of ambient conditions on exhaust emissions, the effectiveness of the test methods and procedures employed to obtain durability data, test methods and aprocedures associated with LDMV evaporative-HC emissions and other related emission information are included in Section 4.0.

Due to the present and projected energy shortages, considerable national attention has been recently focused on the fuel economy of LDMV. Unfortunately, at the present time generally accepted standardized fuel economy test methods and procedures are not available. Section 5.0 summarizes and evaluates information presently available concerning the important factors affecting fuel economy, the advantages and disadvantages of alternate fuel economy test methods and procedures, the statistical variability of fuel economy measurements and the effect of cold-start and ambient temperature on LDMV fuel economy. Finally, Section 6.0 summarizes the conclusions reached during the course of the present study.

3.0 VEHICLE USE PATTERNS AND DRIVING CYCLES

3.1 Introduction

The objective of a driving cycle is to simulate actual driving conditions as accurately as possible within the constraints of time, cost, instrumentation, etc. Light-duty motor vehicles are operated in a complicated sequence of operational modes including idle, acceleration, deceleration, and cruise. The time spent in each mode and the magnitude of the accelerations, decelerations and cruises can vary significantly depending on whether the vehicle is being driven in an urban, suburban, rural or interstate mode. In addition, two drivers traveling the same route under identical traffic conditions are likely to drive in a significantly different manner. Therefore, it is impossible to develop an absolutely typical driving cycle that will accurately represent the way all vehicles are driven.

However, since it has been established that both emissions and fuel economy are dependent on the driving cycle, one or more standardized driving cycles for both emissions and fuel economy testing must be adopted. These cycles will be subsequently utilized to determine if a vehicle meets legislated emissions standards, to evaluate the relative fuel economies of various automotive-design parameters and to compare the economies of one vehicle versus another. The driving cycles should represent, as nearly as possible, actual usage patterns of LDMV. They should be repeatable and capable of being driven easily and accurately.

Considerable effort has been directed toward the development of representative driving cycles for both emissions and fuel economy. In addition, various organizations have attempted to establish typical vehicle-use patterns. Since the establishment of representative driving cycles is an important aspect of both emissions and fuel economy test procedures, the results of these studies are summarized in subsequent paragraphs.

3.2 Vehicle-Use Patterns

Probably the most comprehensive study of LDMV-use patterns was carried out by the Federal Highway Administration during 1969 and 1970. Selected high-lights from this nine-volume report[1*] are summarized below.

The average LDMV is driven 11,600 miles per year. Annual vehicle mileage accumulation is maximum for new vehicles and reduces with vehicle age. The annual mileage accumulation per vehicle increases as the number of vehicles per household increases.

The average household was found to make 3.8 trips per day and the average trip length was approximately 8.9 miles. Trips to work represented approximately one third of all trips made and represented approximately one third of all miles driven by LDMV. The average trip to work is 8.9 miles even though 52% are 5 miles or less.

The percentage of vehicle trips of various lengths as a function of season of the year was also reported in Volume 3 of Reference 1. These results are reproduced in Table 3.1 and the annual distribution of the percent of trips as a function of trip length is graphically represented in Figure 3.1. Inspection of Figure 3.1 indicates that most frequently made trips are less than one mile long.

Since the length of the most frequent trips is very short, most of the vehicle miles traveled (VMT) are accumulated during trips of longer duration. A VMT distribution as a function of trip length may be computed from a knowledge of the frequency of trips as a function of trip length. The distribution of the percent of VMT as a function of trip length is also plotted in Figure 3.1. Direct utilization of the data in Table 3.1, for the computation of the VMT distribution, would result in the noncontinuous plot shown in the insert in Figure 3.1. The VMT distribution represented in Figure 3.1 is based on a smooth curve drawn through the data. The noncontinuous distribution of VMT shown in the insert apparently results from many of the individuals sampled responding with either "5 miles" or "10 miles" as the distance

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*References are listed at the end of the report (page 140).

TABLE 3.1

Percentage of Vehicle Trips by Lengths and Season of Year

Season of the year	Length of trip (miles)																		
	Less than one-half mile	1	2	3	4	5	6	7	8	9	10	11-15	16-20	21-30	31-40	41-50	51-99	100 & over	Total	Daily number of trips (000)
Spring (April)	8.2	16.4 1/	13.0	9.5	6.4 2/	8.8	3.6	2.4	3.5	1.3	5.3	8.8	4.6	4.1	1.7	0.8	0.9	0.7	100.0	254,445
Summer (July-August)	8.4	14.2 1/	13.1	9.7	6.3 2/	8.8	4.3	3.0	3.3	1.3	5.5	8.4	4.5	4.1	1.7	0.9	1.3	1.2	100.0	236,971
Fall (October)	8.7	15.2 1/	14.9	10.0	6.6 2/	7.8	3.7	3.8	3.5	1.0	5.9	7.4	3.7	3.6	1.5	0.9	1.1	0.7	100.0	237,936
Winter (January)	8.8	17.6 1/	13.0	10.6	6.3 2/	7.5	3.8	2.8	3.4	1.0	5.4	7.7	4.4	4.0	1.3	0.8	0.9	0.7	100.0	222,596

1/ Indicates the statistical mode of trip lengths or the most likely length of trip taken.

2/ Indicates the median trip length or where 50% of the trips are longer and 50% are shorter.

SOURCE: Based upon unpublished table T-5 from the Nationwide Personal Transportation Survey conducted by the Bureau of the Census for the Federal Highway Administration, 1969-1970.

REF. 1

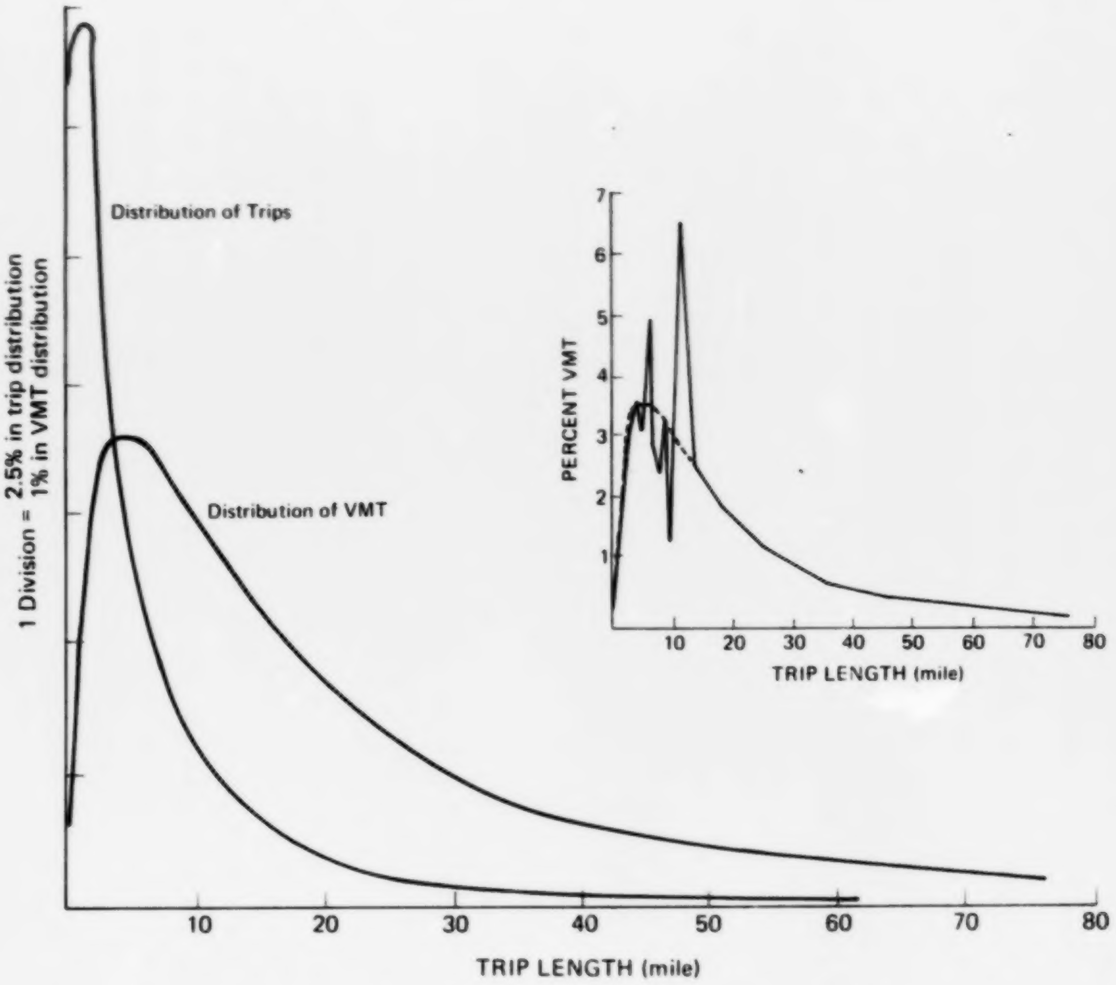

FIGURE 3.1 Distribution of LDMV Trips and Vehicle Miles Travelled

for trips that were close to 5 miles (4 to 7 miles) or close to 10 miles (9 to 13 miles). Inspection of the VMT distribution indicates that more miles are driven for trips within 0.5 miles of 4.5 miles than trips over any other one-mile interval.

It has been reported, based on data from the Federal Highway Administration, that the ratio of rural miles driven to urban miles driven has varied historically due to increased urbanization from 1.1 to approximately 0.82 at the present time.[2]

3.3 Development of Driving Cycles for Emissions

Early work in the 1950's culminated in the development of the California seven-mode cycle. The seven-mode cycle[3] was intended to represent average driving conditions throughout Los Angeles County during both peak and off-peak traffic conditions. Subsequent studies concluded that an emissions driving cycle should not represent twenty-four-hour, county-wide vehicle operation but that it should concentrate on the type of driving that contributed to peak primary pollutant levels in the Los Angeles basin.[4] It was also determined that the major contributor to Los Angeles smog was the morning home-to-work trip, and it was proposed that prevalent operating modes during this trip could be identified and subsequently reproduced on a chassis dynamometer. Once the various driving modes in urban Los Angeles were classified, a continuous road route, which contained segments such that the total route represented the Los Angeles morning trip to work, was developed. A 12-mile-road route, called the "L.A.-4 route," centered on the downtown Los Angeles area, was chosen to simulate weekday morning peak driving conditions. Typical speed profiles of a drive over the L.A.-4 were obtained with a series of test vehicles. Since the average trip length in the Los Angeles area was reported to be 7.5 miles,[5] EPA undertook the development of a 7.5-mile urban dynamometer driving schedule (UDDS) based upon the full L.A.-4 driving cycle. The UDDS[6] is a speed trace consisting of 18 profiles separated by idle periods with 0-39 second durations. This schedule covers 7.45 miles in 1372 seconds for an average speed of 19.5 miles per hour (mph). The speed versus time trace for the UDDS is listed in Reference 7 and the UDDS is graphically represented in Figure 3.2.

More recent studies of urban driving patterns in various metropolitan areas have been carried out to determine if the UDDS is an adequate representation of urban driving. The CAPE-10 project (see References 8 to 11) was designed to determine the average driving cycles in the following 5 major metropolitan areas: Los Angeles, Houston, Cincinnati, Chicago and New York City. The average speed, percent of time in each mode and percent occurrence in each mode as obtained by the CAPE-10 project are presented in Table 3.2. The UDDS and the original L.A.-4 cycle data are also presented in Table 3.2 for the sake of comparison.

Comparison of the CAPE-10 L.A.-4 data designed to represent Los Angeles morning rush-hour traffic (line 8 in Table 3.2) with the original L.A.-4 data (line 11 in Table 3.2) indicates excellent agreement between the two studies. Based on this observation and the good correlation between the UDDS and the original L.A.-4 cycle, it can be concluded that the UDDS is a good representation of morning rush-hour driving patterns for central Los Angeles. Inspection of Table 3.2 also indicates that the UDDS has a lower average speed and more percentage of time in the idle mode than the CAPE-10 five-city composite cycle. It has been reported[12] that there are not significant differences in exhaust emissions of vehicles tested on the five-city composite cycle when compared to the UDDS.

3.4 Development of Driving Cycles for Fuel Economy

Historically, individual automobile manufacturers and other interested parties have developed fuel economy driving cycles to test the effects of vehicle-design changes, fuels and lubricants and other factors on automotive fuel economy. In most cases, fuel economy was

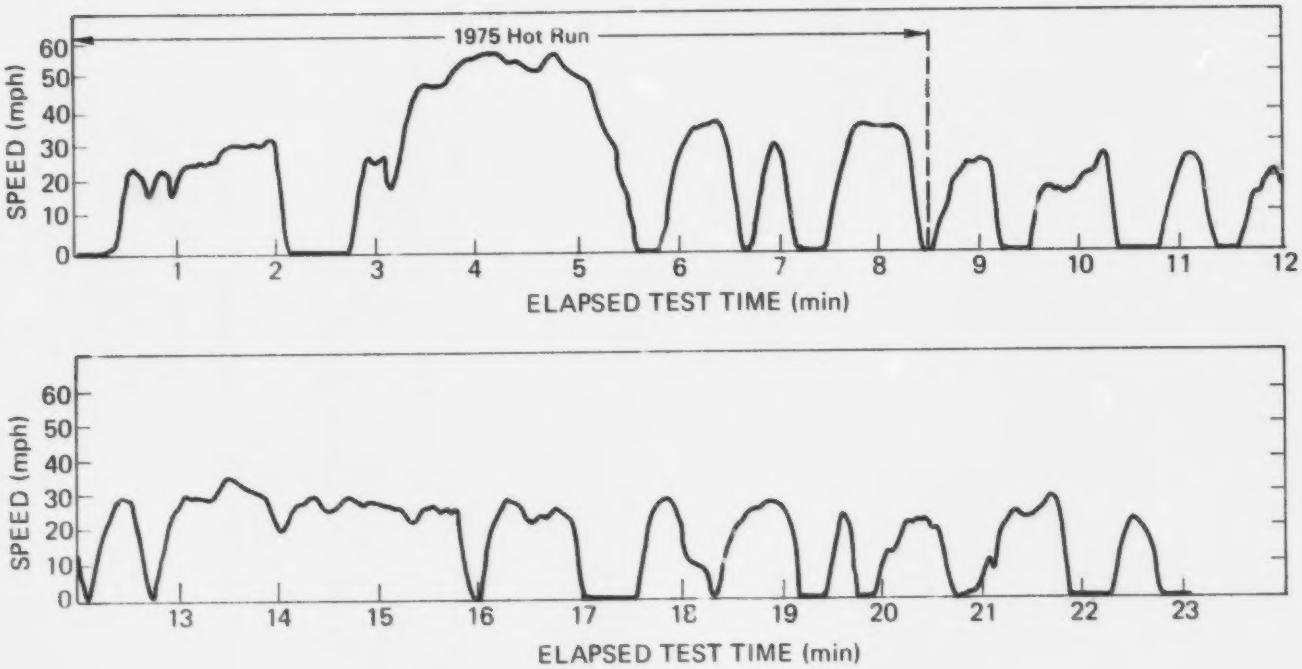

FIGURE 3.2 Speed Versus Time Trace for the UDDS

REF. 7

TABLE 3.2

Comparison of Urban Driving Patterns And Driving Cycles

CYCLE OR CITY	AVERAGE SPEED-MPH	PERCENT TIME IN EACH MODE % IDLE	% CRUISE	% ACCL	% DECEL	PERCENT OCCURANCE IN EACH MODE % IDLE	% CRUISE	% ACCEL	% DECEL
New York City	21.6	17.45	26.49	29.12	26.95	7.60	42.40	25.43	24.57
Chicago	24.5	14.11	30.86	28.30	26.78	7.81	42.19	25.38	24.62
Cincinnati	25.9	11.34	30.72	30.89	27.06	7.42	42.58	25.44	24.57
Houston	27.7	11.30	36.80	27.35	24.58	6.97	43.03	25.43	24.57
Los Angeles	29.3	10.13	34.28	29.78	25.82	7.60	42.40	25.04	24.96
5-City Comp.(1)	25.8	12.87	31.83	29.08	26.23	7.48	42.52	25.34	24.66
5-City Comp.(2)	26.0	13.06	31.50	29.16	26.30	7.59	42.41	25.26	24.74
L.A.-4(3)	21.0	13.56	27.25	31.73	27.49	9.50	40.50	25.26	24.74
L.A.-4(4)	17.4	18.43	25.42	29.82	26.28	10.70	39.30	25.41	24.59
UDDS(5)	19.7	18.2	30.2	27.7	23.9	12.0	38.0	26.7	23.3
Original L.A.-4(5)	20.9	13.6	27.3	31.7	27.5	9.5	40.5	25.3	24.7

(1) Cities weighted equally.

(2) Cities weighted by vehicle registration.

(3) Results are for defined hours 9:00 a.m. - 11:00 a.m. and 1:00 p.m. - 3:00 p.m.

(4) Results are for off-hours 7:00 a.m. - 9:00 a.m. and 3:00 p.m. - 5:00 p.m.

(5) Data from Reference 6.

REF. 6, 10

determined for a series of steady-state cruise modes at various speeds and for vehicle operation over a number of driving cycles designed to simulate consumer driving patterns in the urban, suburban and interstate driving modes. Until recently, a standardized fuel economy driving cycle that might serve as the basis for the accumulation of data on fuel economy of cars for comparison purposes was not available.

The EPA suggested that the UDDS can be utilized as a standardized driving cycle to evaluate urban fuel economy. EPA has published fuel economy data for selected 1973 model-year[13] and 1974 model-year[14] LDMV based on the UDDS (see Figure 3.2 for a speed versus time trace of the UDDS). Significant data have been accumulated for urban fuel economies of LDMV on this cycle.

Since highway travel accounts for approximately 50% of the total vehicle miles traveled, the EPA has recently proposed a highway driving cycle for fuel economy measurements.[15] This cycle was derived by instrumenting a car and driving on four classes of roads in the vicinity of Ann Arbor, Michigan. The velocity time traces obtained as a result of driving these four types of roads were then combined in such a way as to approximate the mileage composition as specified for such roads by the Department of Transportation. For certain belt-driven dynamometers, the initial acceleration and final deceleration proved to be too large. Therefore, EPA reduced these accelerations in a revised driving schedule.[16] The speed versus time trace of the EPA highway driving cycle is presented in Figure 3.3.

The velocity composition of both the EPA urban driving cycle and the proposed highway driving cycle are shown in Figure 3.4.[17] Inspection of Figure 3.4 indicates that both cycles have velocity distributions that are approximately bimodal. That is, during the CVS-CH cycle, most of the cycle distance is traveled at speeds in the vicinity of either 25 or 55 mph, and in the highway driving cycle, most of the distance is traveled at speeds in the vicinity of either 47 or 57 mph.

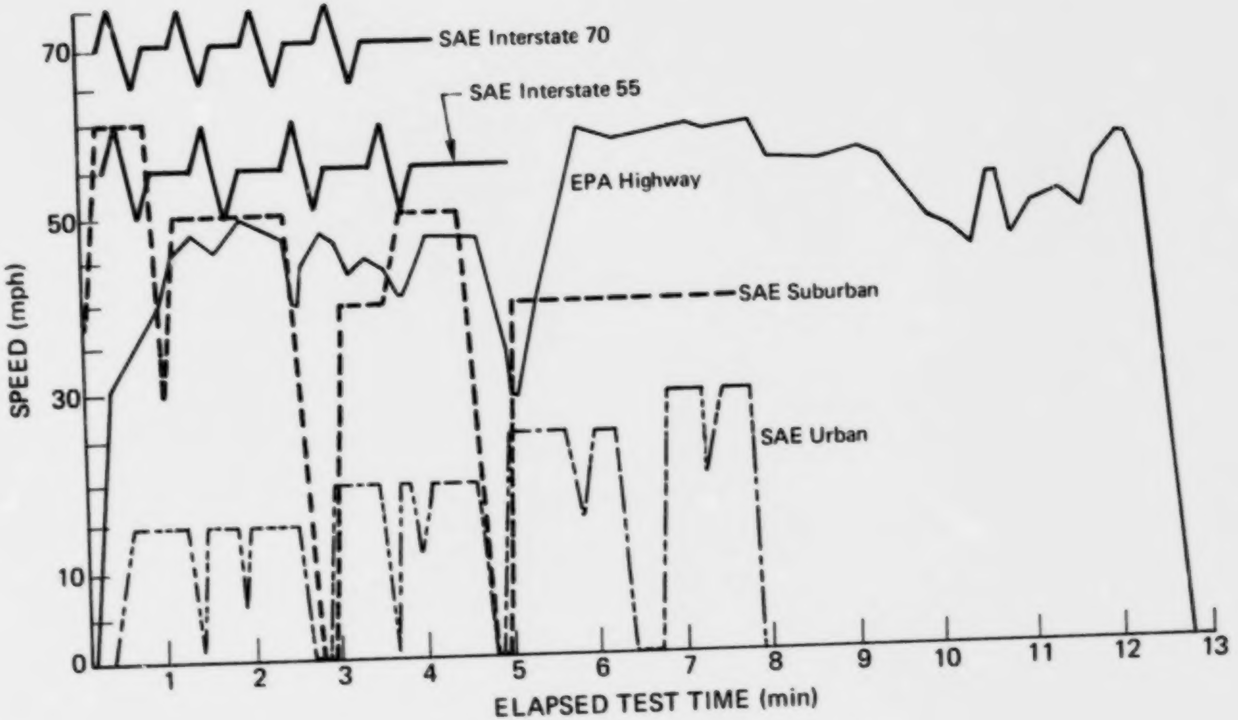

FIGURE 3.3 Comparison of Various Fuel Economy Driving Cycles

REF. 16, 18

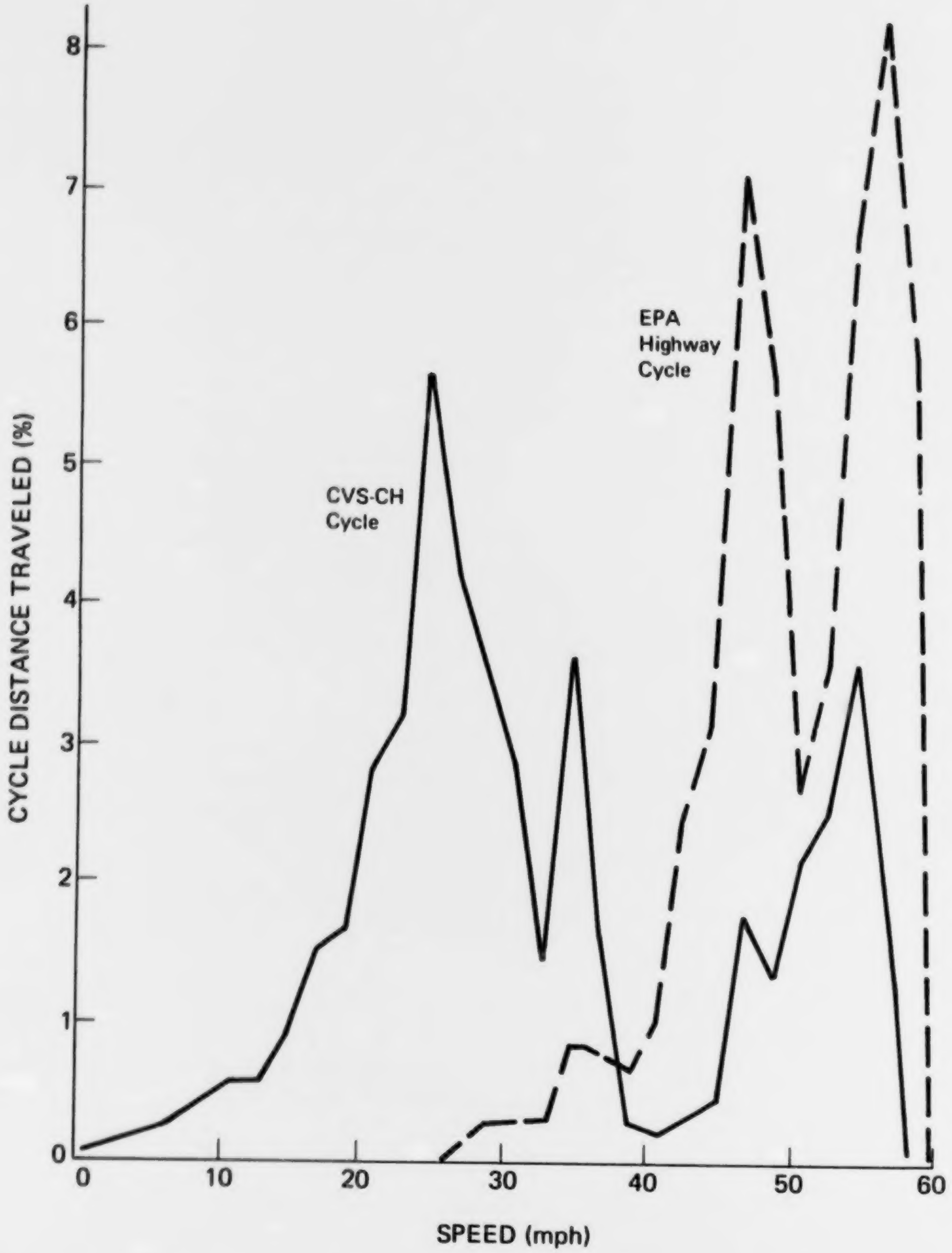

FIGURE 3.4 EPA Urban and Highway Fuel Economy Driving Cycle Velocity Distributions

REF. 17

The Society of Automotive Engineers (SAE) Technical Board has recently created the SAE Fuel Economy Measurement Procedures Task and charged it with a two-phase program to develop fuel economy test procedures and driving cycles and to suggest procedures that can be utilized to evaluate the effect of vehicle parameters on fuel economy.

The SAE Task Force reviewed the various manufacturers' driving cycles, and concluded that these cycles, though not identical, were similar and produced fuel economy values that did not greatly differ. Based on these considerations, the SAE has recommended the adoption of four fuel economy driving cycles[18] including: (a) an urban cycle--designed to simulate driving conditions in the central business district of a large city; (b) a suburban cycle--designed to simulate the driving conditions in suburban areas of a large city; and (c) two interstate cycles, one with an average speed of 55 mph and one with an average speed of 70 mph--designed to simulate driving conditions on an expressway. All of these cycles are detailed in Reference 18, and speed versus time traces for these cycles are shown in Figure 3.2. The important characteristics of the proposed fuel economy driving cycles are listed in Table 3.3.[17]

Inspection of the data listed in Table 3.3 indicates that the primary differences between the EPA urban driving cycle and the SAE urban driving cycle are the average cycle speeds of 21.2 mph and 15.5 mph, respectively, the number of stops per mile, 2.0 and 4.0 respectively, and the percent of time spent in the various driving modes. More than one half of the time in the SAE urban cycle is represented by a cruise condition while only approximately 8% of the time is spent in the cruise mode for the EPA urban cycle. Correspondingly more time is spent in the acceleration, deceleration and idle modes in the UDDS cycle than in the SAE cycle. Since the SAE urban cycle is designed to represent driving in the central business district

TABLE 3.3

Comparison of Current and Proposed Fuel Economy Driving Cycles

	EPA DRIVING CYCLES			SAE DRIVING CYCLES			
START	CVS-C COLD (1972-FTP)	CVS-CH COLD (1975-FTP)	HIGHWAY HOT	URBAN HOT	SUBURBAN HOT	INTERSTATE (55 mph) HOT	INTERSTATE (70 mph) HOT
TEST LOCATION	CHASSIS ROLLS	CHASSIS ROLLS	CHASSIS ROLLS	TRACK	TRACK	TRACK	TRACK
Length (miles)	7.45	11.04	10.25	2.0	5.2	4.7	4.7
Driving Time (min)	22.87	31.3	12.7	7.7	7.6	5.1	4.0
Avg. Speed (MPH)	19.5	21.18	48.8	15.5	41.1	55.3	70.5
Max. Speed (MPH)	56.5	56.5	59.9	30	60	60	75
Max. Accel. (FPS^2)	4.84	4.84	4.69	7.0	7.0	1.0	1.0
Time Cruise %	7.9	7.7	16.5	58.3	75.2	61.8	51.5
Time Accel. %	39.6	39.3	44.4	11.3	11.3	19.1	24.3
Time Decel. %	34.6	34.9	38.7	17.4	10.5	19.1	24.2
Time Idle %	17.8	18.1	0.4	13.0	3.0	0	0
No. of stops per mile	2.3	2.0	0.1	4.0	0.4	0	0

NOTE: Accelerations and decelerations are defined as changes in velocity greater than 0.1 ft/sec^2

REF. 17

of a large city it has more stops per mile than the UDDS urban cycle that is based on the L.A.-4 road route.

The proposed EPA highway cycle is designed to incorporate driving conditions on various classes of highways, including freeways with a 55 mph speed limit, and hence its average speed of 48.8 mph falls between the average speeds of the SAE suburban and the SAE 55 mph interstate cycles. As in the urban cycle, the EPA highway cycle includes considerably more time in acceleration and deceleration modes than either the SAE suburban or interstate cycles. This may be principally due to two factors: (a) EPA data indicate the drivers do not tend to drive at a constant speed but tend to drive at an uneven speed even when they are in an approximate cruise mode; and (b) the SAE driving cycles were developed for road and/or track procedures where cycles based on combination of constant accelerations, decelerations and cruise modes can be most accurately reproduced from test to test. Presently, there is some controversy as to the relative differences in fuel economy of a given vehicle when it is driven at a constant speed as compared to a varying speed centered about the same constant level.

Based on a study of actual vehicle driving patterns in Phoenix and central Arizona, it has been suggested that typical driving patterns may be correlated in terms of the number of stops per mile and average trip speed.[19] This correlation is shown in Figure 3.5 and the proposed fuel economy cycles are plotted in Figure 3.5 for the sake of comparison.

Inspection of these data indicates that all of the proposed fuel economy driving cycles are in agreement with the proposed correlation. Based on these relatively limited data, one should not conclude that the proposed correlation represents all driving patterns. However, any proposed driving cycle that was in significant disagreement with the correlation should be carefully scrutinized.

3.5 Summary

The UDDS, which is presently employed as the official emission

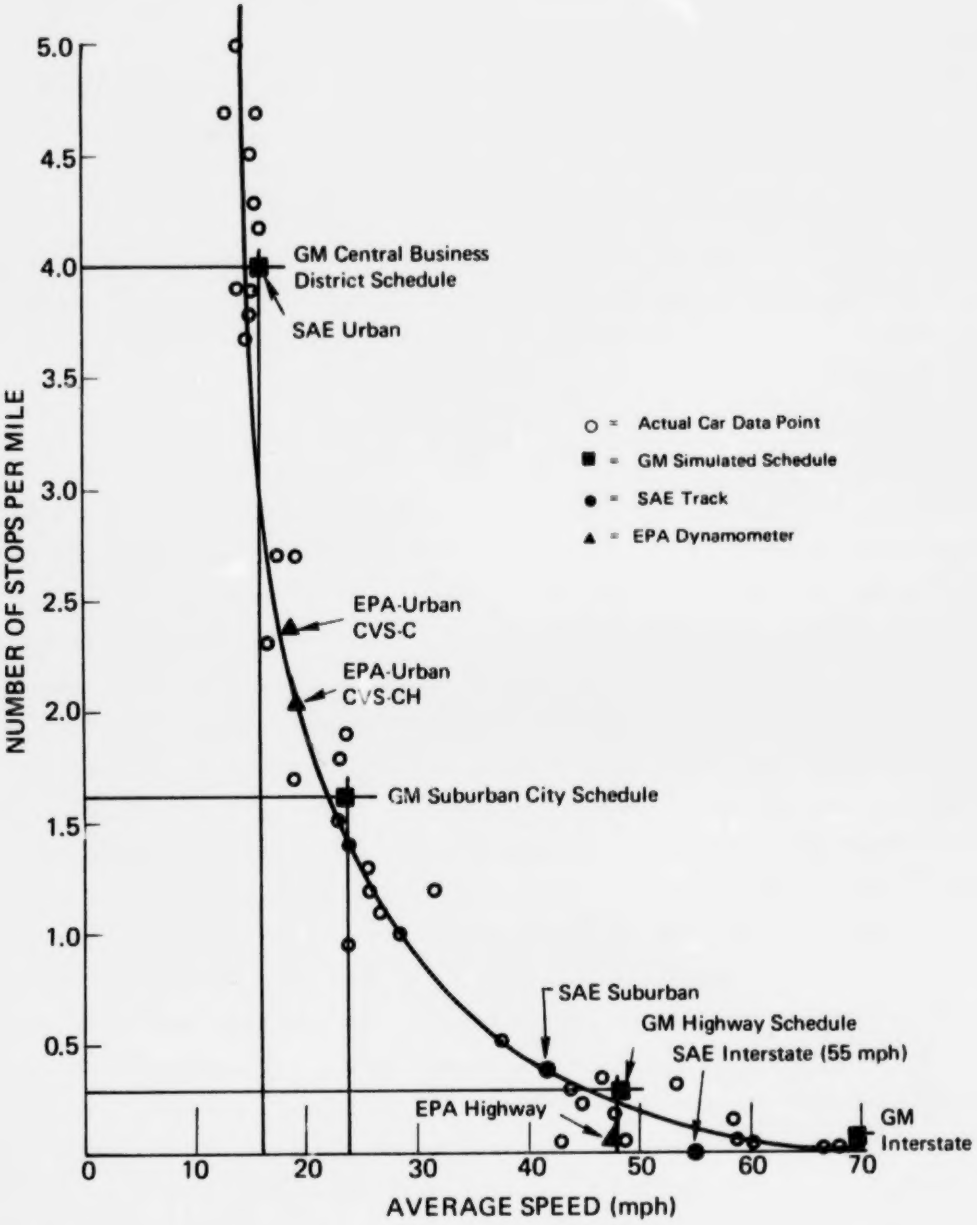

FIGURE 3.5 Proposed Correlation for Fuel Economy Driving Cycles Test Results, Summer, 1971, Phoenix and Central Arizona

REF. 19

driving cycle, is not in complete agreement with the composite driving pattern results obtained recently. However, since it has been shown that emissions in an urban driving cycle are not very sensitive to changes in the cycle, it is concluded that the UDDS cycle represents an average urban trip, as far as emissions are concerned, "as well as it needs to."

Since driving patterns change with time and two drivers would tend to drive the same route in a different manner it is not possible to develop an absolutely typical fuel economy driving cycle. However, since the driving cycle strongly influences fuel economy, it is important to adopt standardized fuel economy driving cycles that can be utilized to evaluate the relative fuel economies of various automotive designs and to compare the economies of one vehicle versus another.

Since significant vehicular miles are accumulated in both urban and nonurban environments, and fuel economies in these two driving modes are significantly different, it is concluded that two standard LDMV fuel economy driving cycles--one designed to represent urban vehicle operation and one designed to represent highway driving--are needed to allow rational consumer choice. Data presently available indicate the fuel economy for a given vehicle is approximately 50% greater for a typical highway cycle than for a typical urban cycle. (See Section 5.2.)

4.0 EMISSION TEST METHODS AND PROCEDURES

4.1 Introduction

In order to enforce the provisions of the Clean Air Amendments of 1970, EPA has established emission standards, the official CVS-CH test method and regulations prescribing requirements a manufacturer must meet before the EPA will grant a Certificate of Conformity. A Certificate of Conformity is required before a manufacturer can produce and sell a specific class of vehicles.

The exhaust-emission standards are summarized below:

MODEL YEAR	HC (g/mi)	CO (g/mi)	NO_x (g/mi)
1974 Federal[1]	3.4	39.0	3.0
1974 Calif.[1]	3.2	39.0	2.0
1975-76 Federal[2]	1.5	15.0	3.1
1975-76 Calif.[2]	0.9	9.0	2.0
1977 Nationwide Standards[2]	0.41[3]	3.4[3]	2.0[4]
1978 Nationwide Standards[2]	0.41	3.4	0.4

The certification procedure for LDMV is based on a combination of results obtained from exhaust-emission tests at low mileage conducted on an emission-data fleet and an estimate of exhaust-emission-control-system-durability data obtained from a durability-data fleet. Both the low mileage emission data and the durability data or deterioration factors for HC, CO and NO_x are based on the CVS-CH test procedure. Therefore, statistical variations in the CVS-CH test procedure play an important role in the certification procedure, and hence the statistical reliability and factors affecting the variability of the CVS-CH test method are considered.

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[1] Based on CVS-C test.

[2] Based on CVS-CH test.

[3] These standards could be delayed for one year by action of the EPA Administrator.

[4] California may seek a waiver for a more restrictive standard for NO_x for the 1977 model year.

Other important factors such as the effect of ambient conditions on exhaust emissions, the effectiveness of the test methods and procedures employed to obtain durability data, test methods and procedures associated with LDMV evaporative HC emissions and other related information are also discussed in subsequent paragraphs.

4.2 Certification Procedure

In order to obtain a Certificate of Conformity for a class of vehicles, the manufacturer must demonstrate that the vehicles meet the appropriate emission standards over the "useful life" of the vehicle. The regulations require a manufacturer to test two separate fleets of prototype vehicles representing models to be sold to the public. The emission-data fleet is intended to determine the emissions of relatively new vehicles. The vehicles in this fleet are driven 4,000 miles to break in the engine and stabilize emissions. The emissions are then measured, using the CVS-CH test procedure. Allowable maintenance on emission-data vehicles is limited to the adjustment of engine idle speed at the 4,000-mile test point.

The second fleet, the durability-data fleet, is designed to determine the capability of the emission-control system to keep emissions below the standards over the expected useful life of the vehicle. Each engine-system combination, which is defined as an engine family-exhaust-emission-control-system combination, in the durability-data fleet is examined separately. The vehicles are driven for 50,000 miles and tested for emissions every 5,000 miles. The procedure for mileage accumulation is the Durability Driving Schedule over a modified AMA route. The maximum speed is 70 mph, and the average is 30 mph.

Scheduled maintenance of durability vehicles may be performed at the same mileage intervals as specified to the consumer. Scheduled major tune-ups to manufacturer's specifications may be performed no more frequently than every 12,500 miles. The replacements and adjustments allowed are detailed in the Regulations. Emission tests must be run before and after any vehicle maintenance that may be reasonably expected to affect emissions. The manufacturer has the option of running more than one durability-data vehicle in each engine-system combination and up to three valid CVS-CH tests at each mileage point may also be run provided that the same number of tests are conducted at each mileage interval. Once a durability-data vehicle is started in the fleet, it must continue to operate unless discontinued by written consent of the EPA Administrator.

All the applicable data generated for each engine-system combination are used to compute separate deterioration factors for HC, CO and NO_x for each engine-system combination in the durability-data fleet. The applicable emission data are plotted as a linear function of mileage and the best straight lines, fitted by the method of least squares, are computed for each set of data. The interpolated 4,000 and 50,000-mile points of the lines must be within the specified emission standards or the data cannot be used for the calculation of a deterioration factor. Deterioration factors for each of the three pollutants for each engine-system combination are subsequently computed by taking the ratio of the emissions at 50,000 miles to the emissions at 4,000 miles from the appropriate least-squares fit line.

Each data car in the emission-data fleet is subsequently tested for certification by multiplying its exhaust-emission test results, obtained after it has been driven 4,000 miles, by the appropriate deterioration factor to obtain the adjusted emissions for the vehicle. These adjusted emissions are then compared to the standards, and if the adjusted emissions for all pollutants are below the appropriate standards, the car passes; if not, it fails. In the event that the car fails, it may be tested a second time. If the car passes the second test, it is considered to have certified. Every emission-data car in an engine family must pass the certification procedure before the family can be certified.

The CVS-CH test method is utilized for measuring true mass emissions for 1975 model-year and later vehicles. The vehicle is tested on a chassis dynamometer after a temperature-conditioning period of at least 12 hours between 60°F and 86°F. The key is turned on and exhaust gas sampling begins immediately, whether the engine starts or not, and continues until the engine stops. The entire exhaust gas stream is mixed with purified ambient air and passed through a heat exchanger to make a constant volume flow of variably diluted exhaust gas. Samples, drawn at a constant rate from this diluted stream, are collected and analyzed for HC, CO, NO_x and CO_2 by specified methods. The driving cycle for the CVS-CH test is based on the UDDS. The test is initiated from a cold start, and after deceleration ends at 505 seconds (see Figure 3.2), the diluted exhaust flow is switched from the "cold transient bag" to the "stabilized bag." Diluted exhaust is collected in the stabilized bag during the remainder of the 1372-second driving cycle. After a 10-minute shutdown, the engine is restarted in a hot condition and the first 505 seconds, or the transient phase, of the driving cycle is repeated. During this phase of the test, the diluted exhaust is collected in the "hot transient bag." During the "stabilized phase" of the hot-start run, it is assumed that the vehicle would produce the same emissions as were produced during the stabilized phase of the cold-start cycle. Therefore, it is not necessary to repeat the stabilized phase of the hot-start cycle. Emissions in the cold transient bag and hot transient bag are weighted and are added to the emissions in the stabilized bag to obtain the CVS-CH mass emissions. These weighting factors reflect the EPA's estimate that 43% of the vehicle trips, on a national average, are initiated from a cold start. Complete descriptions of the CVS-CH test method may be found in the literature.[20,21]

The CVS-C test method was employed for emission testing on vehicles in model years 1972, 1973 and 1974. The CVS-C test is very similar to the CVS-CH test except that all emissions are collected in a single bag and the hot transient phase of the test is eliminated. The CVS-H test is also employed to measure emissions from a fully warmed-up vehicle. In this test, the vehicle is fully warmed-up prior to initiating the CVS-C test.

It is possible to estimate the probability that a given emission-data car or an entire engine family will pass the certification procedure assuming that the statistical variations associated with the vehicles and test procedures follow a normal probability distribution. In order to make these computations, it is necessary to have data concerning the variability (s_i) relative to the true adjusted emission mean ($\bar{x}_i$) and the ratio of the true adjusted emission mean ($\bar{x}_i$) to the appropriate emission standard (A_i). The true adjusted emission mean ($\bar{x}_i$) is defined as:

$$\bar{x}_i = DF_i \; (\bar{x}_i)_{4K}$$

DF_i = Appropriate deterioration factor for vehicle under consideration and pollutant, i

$(\bar{x}_i)_{4K}$ = True mean emission value of pollutant i for emission-data car at 4,000 miles.

i = subscript corresponding to HC, CO or NO_x

The following probability parameters are defined:

P_i (1) - the probability of a single pollutant i being below the standard for one test.

P_i (2) - the probability of a single pollutant i being below the standard in at least one out of two tests.

P (2,3,1) - the probability that all three pollutants (HC, CO and NO_x) are simultaneously below the appropriate standards at the same time in at least one out of two tests for a single vehicle. For the special case where the three pollutants are independent and the values of $(s_i/\bar{x}_i)$ and $(\bar{x}_i/A_i)$ are the same for each pollutant, the symbol P*(2,3,1) is used.

P (2,3,4) - the probability that all three pollutants (HC, CO and NO_x) are simultaneously below the appropriate standards in at least one out of two tests for four independent vehicles in an engine family. For the special case where the three pollutants are independent and $(s_i/\bar{x}_i)$ and $(\bar{x}_i/A_i)$ values are the same for each pollutant, the symbol P* (2,3,4) is used.

The results listed in Table 4.1a, which are based on an assumed normal probability distribution, can be utilized to determine the various probabilities, in percent, listed above as a function of the two parameters $(\bar{x}_i/A_i)$ and $(s_i/\bar{x}_i)$. The main body of Table 4.1a, contained within the solid lines, represents specific values of a vehicle's true adjusted emission mean dividied by the appropriate emission standard, $(\bar{x}_i/A_i) = (DF_i)(\bar{x}_i)_{4K}/A_i$, in percent. The numerical values in the far left-hand column of the Table represent specific values of the parameter $(s_i/\bar{x}_i)$ in percent. Numerical values of $P_i(1)$, $P_i(2)$, P* (2,3,1) and P* (2,3,4) in percent are obtained from Table 4.1a as functions of $(s_i/\bar{x}_i)$ and $(\bar{x}_i/A_i)$. The equations used for calculating the entries in the Table are listed in Table 4.1a.

The utility of Table 4.1a can be illustrated by considering some examples:

i. Determine the required value of the true, adjusted emission mean as a percent of the appropriate standard ($\bar{x}_i/A_i$ in %)

TABLE 4.1a

Table of Ratio of True Adjusted Mean Emission to Standard in Percent, $\bar{x}_i/A_i\%$, as a Function of $s_i/\bar{x}_i$ in Percent and Probability in Percent.

	$P_i(1)\%$	50	55	60	65	70	75	80	85	90	92.5	95.0	97.5
	$P_i(2)\%$	75.0	79.8	84.0	87.8	91.0	93.8	96.0	97.8	99.0	99.4	39.8	99.9
	5	100	99.4	98.8	98.1	97.4	96.7	96.0	95.1	94.0	93.3	92.4	91.1
	10	100	98.8	97.5	96.3	95.0	93.7	92.2	90.6	88.6	87.4	85.9	83.6
	15	100	98.2	96.3	94.5	92.7	90.8	88.8	86.5	83.9	82.2	80.2	77.3
	20	100	97.6	95.2	92.9	90.5	88.1	85.6	82.8	79.6	77.6	75.2	71.8
$\frac{s_i}{\bar{x}_i}\%$	30	100	96.4	92.9	89.6	86.4	83.2	79.8	76.3	72.2	69.8	67.0	63.0
	50	100	94.1	88.8	83.9	79.2	74.8	70.4	65.9	60.9	58.1	54.9	50.5
	75	100	91.4	84.1	77.6	71.8	66.4	61.3	56.3	51.0	48.1	44.8	40.5
	100	100	88.9	79.8	72.2	65.6	59.7	54.3	49.1	43.8	41.0	37.8	33.8
	150	100	84.2	72.5	63.4	56.0	49.7	44.2	39.1	34.2	31.6	28.8	25.4
	$\overset{*}{P}(2,3,1)\%$	23.4	30.5	38.5	47.4	56.8	66.6	76.2	85.1	92.7	95.7	98.0	99.5
	$\overset{*}{P}(2,3,4)\%$	.3	.9	2.2	5.0	10.4	19.6	33.7	52.5	73.7	83.7	92.1	97.9

for a normal distribution

$$P_i(1) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t_i} e^{-y^2/2}\, dy$$

$$t_i = (A_i - \bar{x}_i)/s_i$$

$$P_i(2) = 1 - [1 - P_i(1)]^2$$

(a) for independent emission types

$$P(2,3,1) = 1 - [1 - \underset{HC}{P(1)}\underset{CO}{P(1)}\underset{NO_x}{P(1)}]^2$$

(b) if each emission type has the same values of $s_i/\bar{x}_i$ and $\bar{x}_i/A_i$

$$\overset{*}{P}(2,3,1) = 1 - [1 - (P_i(1))^3]^2$$

This $\overset{*}{P}(2,3,1)$ is given in the table.

(c) if each vehicle has the same $s_i/\bar{x}_i$ and $\bar{x}_i/A_i$ with assumptions (a) and (b)

$$\overset{*}{P}(2,3,4) = [\overset{*}{P}(2,3,1)]^4$$

$$\bar{x}_i = DF_i\,(\bar{x}_i)_{4k}$$

such that P_i (1) is 95% if the standard deviation as percent of the true mean, $(s_i/\bar{x}_i)$, is 50%. Inspection of Table 4.1a indicates that the required value of $(\bar{x}_i/A_i)$ is 54.9%.

ii. Determine $P_i(2)$ if the standard deviation divided by the mean, $(s_i/\bar{x}_i)$, is 30% and $(\bar{x}_i/A_i)$ is 89.6%. In this case $P_i(2)$ is equal to 87.8%.

Numerical examples associated with P* (2,3,1) and P* (2,3,4) can be obtained from Table 4.1a in a similar manner. However, due to the previously outlined assumptions required to calculate these values, these quantities are only rough approximations at best. More accurate predictions of P(2,3,1) and P(2,3,4) can be obtained for a specific case, assuming independent emissions, by combining the values of $P_i(1)$, $(s_i/\bar{x}_i)$ and $(\bar{x}_i/A_i)$ for each pollutant with the equations for P(2,3,1) or P(2,3,4) listed in Table 4.1a.

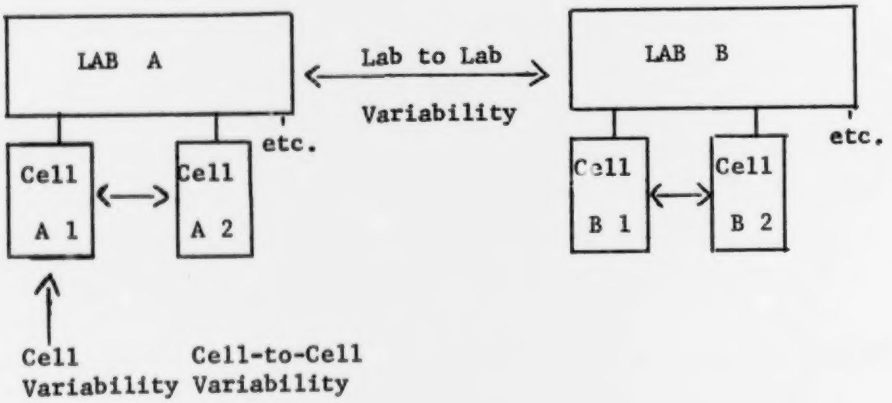
4.3 Statistical Variability of Exhaust-Emission Measurements

Exhaust-emission measurements at 1975-76 levels tend to have poor reproducibility. Both systematic and random errors associated with vehicle variability, emissions collection and measurement variability and environmental variables contribute to the poor test reproducibility. In addition to these variations associated with a given vehicle, variations in emissions from a group of similar production vehicles are encountered.

As shown in Table 4.1,[23] there are basically three levels of variability associated with the measured exhaust emissions for a given vehicle. These are the variability associated with a given test cell, cell-to-cell variability within a given laboratory site and the basic laboratory-to-laboratory variability. The most important factors affecting exhaust-emissions variability at each of these three levels are also listed in Table 4.1. Since vehicle variability is an important factor at all levels, various programs have been carried out that

TABLE 4.1

Factors Affecting Exhaust Emissions Variability of a Given Vehicle at Various Levels


LAB A
Lab to Lab
Variability
LAB B
etc.
etc.
Cell
A 1
Cell
A 2
Cell
B 1
Cell
B 2
Cell
Variability
Cell-to-Cell
Variability

MAJOR SOURCES OF EACH LEVEL OF VARIABILITY

Sources	Cell	Cell-to-Cell	Lab-to-Lab
	Vehicle	Vehicle	Vehicle
	Driver	Driver	Driver
	Ambient Condition	Ambient Condition	Ambient Condition
		Dynamometer	Dynamometer
		CVS	CVS
		Analyzer	Analyzer
		Operator	Operator
			Calib. Gas
			Computer

REF. 23

are designed to minimize the importance of vehicle variability on the total emissions variability in order to evaluate cell-to-cell and laboratory-to-laboratory variability. In general, these tests have been carried out by measuring the exhaust emissions of a "hot" or fully warmed-up vehicle on the federal driving cycle. Data obtained in this manner, subsequently referred to as CVS-H data, are compared to data obtained on the CVS-C and CVS-CH cycles whenever possible. Data obtained during the course of the present study, designed to assess exhaust-emission variability, are presented below.

During early 1972, EPA[22] carried out 30 CVS-CH tests on a 1971 Ford Ranch Wagon with a 429 CID V-8 automatic transmission, air conditioning, evaporative-emission control and a 4-bbl carburetor to determine the exhaust-emission variability of a single vehicle tested in the same test cell. The same CVS system and analytical equipment were used throughout the project. The mean and standard deviation for bag 1, bag 2, bag 3 and the composite value for HC, CO, CO_2 and NO_x of all 30 tests are presented in Table 4.2. The environmental conditions in the test cell during the course of the test program are also summarized in Table 4.2.

Inspection of these results indicates that the standard deviation of the composite value for 30 tests ranged from a low of approximately 2% of the mean for CO_2 to a maximum value of approximately 14% of the mean for HC. (It should be noted that this vehicle has mean emissions higher than the 1975-76 emission standards.)

The emissions were correlated with relative humidity, ambient temperature and barometric pressure. It was reported that a strong correlation was found between all CO mass emissions, except for the cold-start phase, and barometric pressure. NO_x cold-start and stabilized mass emissions correlated with ambient temperature and NO_x stabilized and hot-start emissions were found to correlate with relative humidity.

TABLE 4.2

Summary of Emissions Results for 30 Tests on a 1971 Ford Ranch Wagon in a Single Test Cell

Variable	Mean g/mi	Standard Deviation g/mi	Standard Deviation As % of Mean
Bag 1 (cold transient)			
HC	4.74	1.44	30.46
CO	35.92	6.62	18.43
CO_2	813.33	18.92	2.33
NO_x	5.72	0.49	8.65
Bag 2 (stabilized)			
HC	1.50	0.15	10.25
CO	10.24	1.46	14.28
CO_2	915.43	24.00	2.62
NO_x	3.87	0.26	6.86
Bag 3 (hot transient)			
HC	2.51	0.13	5.18
CO	14.64	1.91	13.02
CO_2	718.01	18.62	2.59
NO_x	5.56	0.41	7.43
Composite (CVS-CH)			
HC	2.46	0.35	14.22
CO	16.73	1.90	11.34
CO_2	840.55	17.30	2.06
NO_x	4.71	0.31	6.48

Summary of Environmental Conditions

Condition	Mean	Standard Deviation	Standard Deviation As % of Mean
Barometric Pressure, in. Hg.	29.32	0.32	1.08
Temperature, °F	74.73	2.05	2.74
Relative Humidity, %	39.93	13.62	34.11

REF. 22

The results of a series of 16 CVS-CH tests carried out on a Chevrolet Impala equipped with a 350 CID engine, a 4 bbl carburetor, air injection, EGR and an oxidizing catalyst are summarized in Table 4.3.[23] These experiments were carried out in the same test cell at constant ambient conditions with the same driver and bench operator in order to determine the repeatability of a catalyst-equipped vehicle operating at emission levels near the interim 1977 emission standards. Inspection of these results indicates that the standard deviation ranges from a low value of approximately 1% for CO_2 to a high of approximately 30% for HC. Other data provided by General Motors[24] for test-to-test variability of CVS-CH tests in a single test cell for experimental vehicles with emissions near 1977 interim levels are summarized in Table 4.4.

Exhaust-emission tests on the CVS-CH test for a group of vehicles equipped with 2.0 liter CVCC stratified-charge engines in various test cells at a given laboratory are summarized in Table 4.5.[25] Inspection of these results indicates that for these low-mileage vehicles, which have emissions near the 1978 Federal Standards, the reported standard deviation as percent of the mean is in the range of 7% to 13%, 2.5% to 7.5% and 3% to 5% for HC, CO and NO_x, respectively.

Data provided by Chrysler Corporation[26] for a specific 1973 model-year production vehicle that has been periodically tested on the CVS-H test in a number of test cells are listed in Table 4.6. Inspection of these data indicates that emission variability in a single cell is in the range of 5% to 35% even for CVS-H tests.

Chrysler Corporation[26] also reported the mean and standard deviation as percent of the mean for exhaust emissions of 90 tests of the same vehicle as discussed in the preceding paragraph at five test cells to be 1.46 ± 13.5%, 11.30 ± 27.1%, 2.23 ± 9.3% and 780.4 ± 4.7% g/mi for HC, CO, NO_x and CO_2, respectively. Comparison of these results with the data listed in Table 4.6 indicates that the mean value and standard deviation for the composite cell-to-cell emissions lies between the maximum and minimum values obtained in the various individual cells.

TABLE 4.3

Summary of Emission Results for 16 Tests on a Chevrolet Impala Equipped with an Oxidizing Catalyst in a Single Test Cell

Variable	HC	CO	NO_x	CO_2
Composite-CVS-CH Emissions (g/mi)	0.37	4.44	2.32	862.1
Standard Deviation (Percent of Mean)	27	17	3.4	1.2
Contribution to Total Grams from "Cold Transient" Phase (percent)	87	94	33	--
Contribution to Overall Standard Deviation in "Cold Transient" Phase	99	99	25	--

REF. 23

TABLE 4.4

Summary of Emissions Test Variability for Three Experimental Vehicles with 1975 Control Systems in a Single Test Cell[1]

Vehicle Serial No.	No. of Tests	HC		CO		NO_x	
		$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$
1	10	0.27	11.1	3.65	26.3	2.72	8.5
2	11	0.34	11.8	0.82	24.4	1.79	5.6
4	11	0.36	16.7	1.97	40.6	1.42	14.1

---

[1] $\bar{x}$ – mean emission value on CVS-CH test, g/mi

$\frac{s}{\bar{x}}$ – standard deviation as percent of mean

REF. 24

TABLE 4.5

Summary of Emission Test Variability for Stratified Charge CVCC Vehicles[1]

Test Cell	No. of Tests	HC		CO		NO_x		CO_2	
		$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$
A	5	0.245	9.0	1.97	2.6	0.460	4.4	423.9	2.1
B	10	0.294	8.1	2.71	5.4	0.260	4.7	476.3	2.5
B	5	0.326	7.8	2.71	1.5	0.356	3.5	454.4	2.6
C	7	0.273	6.9	2.53	7.6	0.309	4.2	509.2	1.5
C	10	0.325	13.2	2.98	6.1	0.383	3.4	454.0	2.2

---

[1] $\bar{x}$ – mean emission value on CVS-CH test in g/mi

$\frac{s}{\bar{x}}$ – standard deviation as percent of mean

REF. 25

TABLE 4.6

Summary of Emission Test Variability for a 1973 Model Year Production Vehicle in Various Test Cells at a Single Laboratory[1]

Test Cell	No. of Tests	HC		CO		NO_x		CO_2	
		$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$
1	14	1.7	8.9	11.6	20.9	2.5	17.4	776	2.8
2	13	1.5	14.7	10.1	33.0	2.1	8.6	751	3.9
3	18	1.45	12.6	11.8	28.1	2.3	8.9	797	3.0
4	18	1.45	12.9	11.0	32.0	2.1	13.7	768	4.0
5	14	1.43	13.9	12.7	23.5	2.2	5.0	790	6.7

---

[1] $\bar{x}$ – mean emission value on CVS-H test in g/mi

$\frac{s}{\bar{x}}$ – standard deviation as percent of mean

REF. 26

A vehicle equipped with an oxidizing catalyst has been tested several times over the CVS-CH cycle in various cells at Chrysler Corporation and three times in one test cell at EPA in Ann Arbor. The results of these data are summarized in Table 4.7.[26] Inspection of these data indicates that the mean values obtained at the two laboratories vary by approximately 25% for HC and CO, are equal for NO_x and within 3% for CO_2.

Honda[25] has reported the results of CVS-CH tests on 38 production vehicles equipped with 1.5 liter CVCC stratified-charge engines. The mean values and standard deviation as percent of mean for HC, CO and NO_x were reported to be 0.23 ± 21.8%, 2.24 ± 8.9% and 1.15 ± 10.4% g/mi, respectively.

General Motors Corporation has developed REPCA I, a vehicle with emissions near the 1974 standards,that is designed to minimize vehicle variability during CVS-H tests. This vehicle has been subsequently utilized in hot tests to obtain information concerning cell-to-cell variability at one laboratory and for round-robin testing between laboratories. Emission data obtained from CVS-H tests on REPCA I in five test cells at General Motors during May 1974[23] indicate that the standard deviation of cell-to-cell variation of emissions measured on CVS-H tests on this specially designed stable-emission vehicle is of the order of 4.5% for HC and NO_x, 8% for CO and 1.8% for CO_2.

The Motor Vehicle Manufacturers Association (MVMA) conducted a lab-to-lab cross-correlation program using CVS-H tests on REPCA I during 1974.[23] These tests were carried out at General Motors, EPA in Ann Arbor, Chrysler, American Motors, Ford and International Harvester during March and April 1974. Most of these CVS-H test results for HC, CO and NO_x, except for one laboratory, fell within plus or minus two standard deviations of the mean values. Standard deviations as percent of the mean for these pollutants were approximately 4.5%, 8.0% and 1.8%, respectively. The CO_2 test results indicated that a number of

TABLE 4.7

Summary of Emission Test Variability for a Catalyst Equipped Vehicle at Two Laboratories[1]

Laboratory	No. of tests	No. of Cells	HC		CO		NO_x		CO_2	
			$\bar{x}$	$\frac{s}{x}$	$\bar{x}$	$\frac{s}{x}$	$\bar{x}$	$\frac{s}{x}$	$\bar{x}$	$\frac{s}{x}$
Chrysler	16	4	0.54	27.8	7.0	25.8	2.65	2.2	667.2	10.6
EPA	3	1	0.43	4.9	5.6	19.7	2.65	3.3	647.9	2.1

---

[1] $\bar{x}$ – mean emission value on CVS-CH test in g/mi

$\frac{s}{x}$ – standard deviation as percent of mean

REF. 26

laboratories were measuring CO_2 values that fell outside the mean plus or minus two standard deviations. The CO_2 standard deviation as percent of the mean was approximately 1.8%. This may be due to systematic errors associated with CO_2 measurements that are encountered in some laboratories.

Klingenberg et al.[27] have reported the results of a round-robin emission test carried out on a "relatively stable" vehicle at various laboratories in the USA and at Volkswagen AG in Germany during 1973. The results of these tests are presented in Figure 4.1. In order to permit comparison between the data obtained, the mean value and standard deviation first obtained for 13 tests at VW AG are plotted in Figure 4.1. Inspection of these data indicates that the values obtained at some laboratories do not fall within the mean plus or minus two standard deviations. A t-test was performed on all measurements obtained and the computations indicated that the results of the tests differ significantly among the different laboratories. It was reported that at the time these data were collected some of the mean values obtained were suffering from systematic errors amounting in some cases to as much as 30%.

The MVMA[28] reported the results of a study designed to compare the emissions data variability of the CVS-CH versus the CVS-C test procedure. The data utilized in this study were obtained from the Single Catalyst Fleet Riverside data from Ford Motor Company's status report to EPA dated October 13, 1972, the 1973 MVMA Correlation Cross Check Program data and 1973 California 2% quality audit data.

A fleet of eight vehicles representing four engine families (two vehicles per family), equipped with 1975-type single-catalyst emission systems was tested by Ford Motor Company as part of the Riverside test program. This program involved conducting back-to-back CVS-CH tests on the eight vehicles at each of the mileage intervals prescribed by the Federal Durability Test Procedure. These tests were conducted at a single facility under highly controlled test conditions, and, consequently,

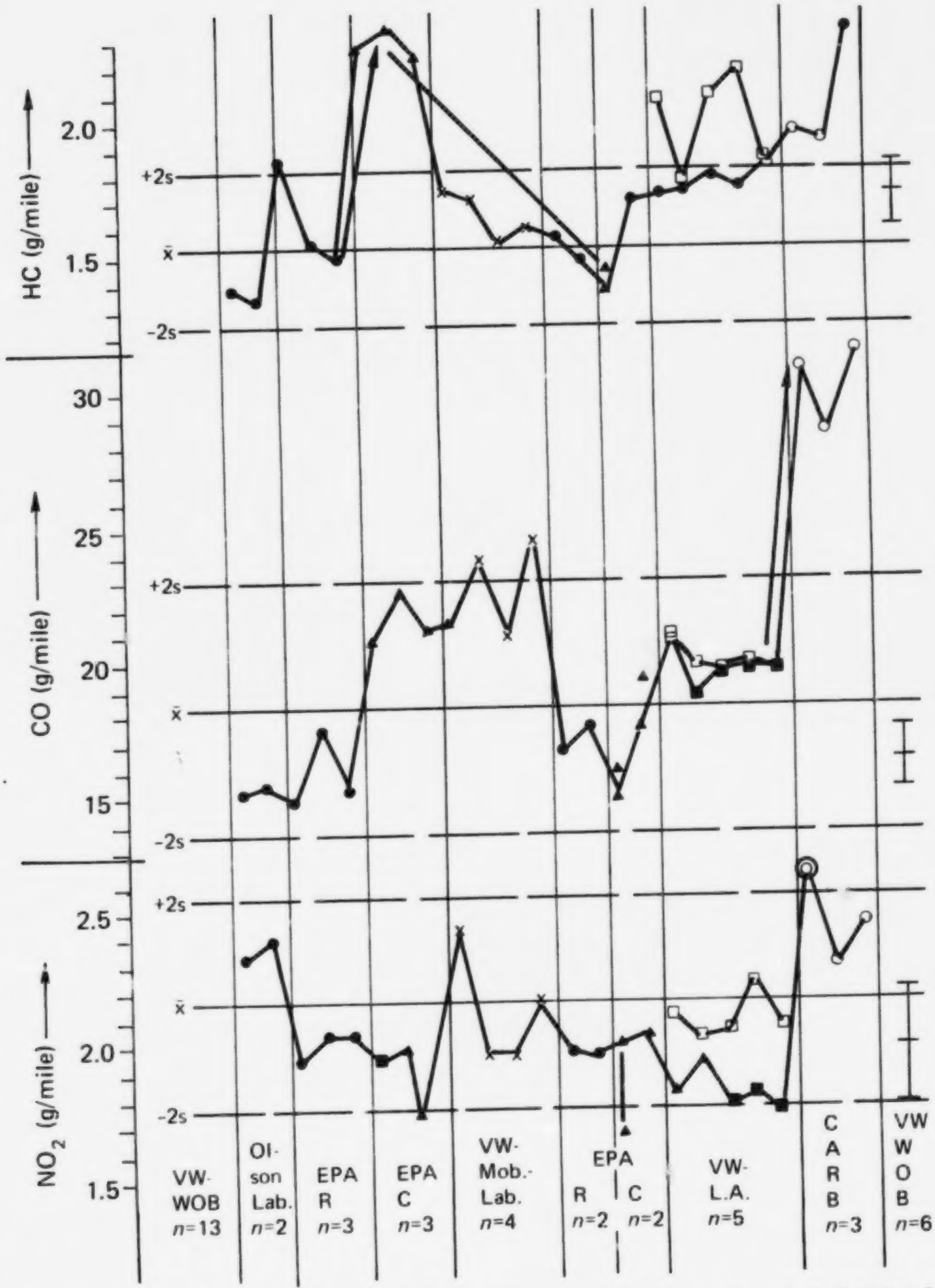


FIGURE 4.1 Lab-to-Lab Emissions Correlation Test for a Relatively Stable Vehicle

REF. 27

the estimated 1975 test variability is considered to be a conservative measure of the test variability which will be encountered during the 1975 Certification Program.

This analysis estimates the test-to-test variability of a 1975-type emission-reduction system based on the back-to-back test data. The before and after-maintenance data were treated as two separate populations in order to prevent emission-level differences due to maintenance from affecting standard deviation calculations. By pooling the standard deviations for mileages, vehicles and families, this analysis separates test-to-test variability from the influences due to mileage, vehicle, family and maintenance. The results of the Riverside test program by engine family are summarized in Table 4.8.[28]

The MVMA carried out a 1973 Certification Program as part of the MVMA Correlation Cross Check Program. This program compared emission results of respective member-company tests to emission results obtained at EPA laboratories. Data were collected from over 300 vehicles from four member companies which indicated that the standard deviation of CVS-C tests as percent of mean emission values were approximately 17%, 23% and 14% for HC, CO and NO_x, respectively. Since these variabilities were in the same range as the Riverside fleet-data variabilities presented in Table 4.8, MVMA concluded that statistical variability of the CVS-CH test for vehicles designed to meet the 1975 standards would be approximately equal to that experienced on the CVS-C test during the course of the 1973 certification testing.

Data provided by one manufacturer[23] summarizing the results of recent CVS-C quality audit tests of 1974 California production vehicles as a function of engine family are summarized in Table 4.9. Inspection of these results indicates that the variability expressed as the standard deviation as a percent of the mean for these production vehicles is in the range of 15% to 30%, 20% to 40% and 15% to 25% for HC, CO and NO_x, respectively.

TABLE 4.8

Summary of Emission Test Data for CVS-CH Tests on the "Riverside" Catalyst Equipped Fleet[1]

Engine Family	HC		CO		NO_x	
	$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$	$\bar{x}$	$\frac{s}{\bar{x}}$
A	0.748	29	4.50	20	2.55	13
B	0.586	9	5.37	31	2.51	8
C	0.423	17	2.69	24	2.32	9
D	0.679	9	4.21	17	2.90	8
Fleet	0.607	19	4.19	26	2.56	10

---

[1] $\bar{x}$ – grand mean of emissions on CVS-CH test, g/mi

$\frac{s}{\bar{x}}$ – standard deviation as percent of the mean

REF. 28

TABLE 4.9

Summary of General Motors Exhaust Emission Audit Tests in California for the Period 1/1/74 thru 3/31/74[1]

Make	Engine Family	No. of tests	HC $\bar{x}$	HC $\frac{s}{\bar{x}}$	CO $\bar{x}$	CO $\frac{s}{\bar{x}}$	NO_x $\bar{x}$	NO_x $\frac{s}{\bar{x}}$
Chevrolet	A1	198	1.9	22	21	24	1.6	19
	A2	130	2.0	19	24	27	1.5	19
	A3	234	1.7	32	26	29	1.5	21
	A4	844	1.8	26	29	32	1.4	21
	A5	63	1.9	36	28	32	1.5	23
Pontiac	B1	91	1.9	18	28	23	1.5	22
	B2	3	1.9	8	16	10	1.5	15
	B3	46	2.4	16	23	49	1.5	15
Oldsmobile	C1	75	2.5	19	24	38	1.5	17
	C2	46	1.6	31	21	29	1.4	24
Buick	D1	48	2.4	25	23	40	1.5	21
	D2	49	2.2	25	27	22	1.2	15
	D3	27	2.6	23	23	21	1.7	15
Cadillac	E1	109	2.1	32	24	40	1.8	36

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[1] $\bar{x}$ g/mi

$\frac{s}{\bar{x}}$ standard deviation as percent of mean

REF. 23

4.4 Factors Affecting Statistical Variability of Exhaust-Emission Measurements in CVS-CH Tests

A schematic diagram of the relationship between the various factors influencing the overall uncertainty of measured mass emissions for a given CVS-CH test is shown in Figure 4.2. (See Section 4.2 for a description of the CVS-CH test.) Inspection of Figure 4.2 indicates that the overall uncertainty of mass emissions is due to the uncertainty in measurement of both the concentration of the pollutants and the volume of gas collected in the exhaust sample bags.

General Motors Corporation[23] has estimated the sources of variability and the probable relative contribution for mass-emission errors in the CVS-CH test as shown in Figure 4.3. These results are based on tests of four vehicles with HC, CO and NO_x emissions ranging from 0.2 to 0.4, 2.0 to 4.4 and 1.0 to 2.4 g/mi, respectively.

Klingenberg et al.[27] have recently discussed errors associated with the CVS-CH test and concluded that the overall measuring uncertainty will be largely due to vehicle variability if the vehicle variability is in the range of 10% to 20% of its mean emission value. They also concluded that the other factors influencing the uncertainty in mass-emission measurements will predominate the overall measuring uncertainty only when vehicle variability is less than approximately 5% of its mean emission value.

The Ford Motor Company created an emissions correlation task force in October 1973[29] and charged it with the responsibility of evaluating the importance of various factors on the variability of vehicle mass-emission measurements. The results of a three-phase program, including audits of emission-test facilities at various laboratories, development and implementation of a statistically designed program to assign priorities to and quantify factors that significantly affect emission-test results and a correlation test program have been reported.

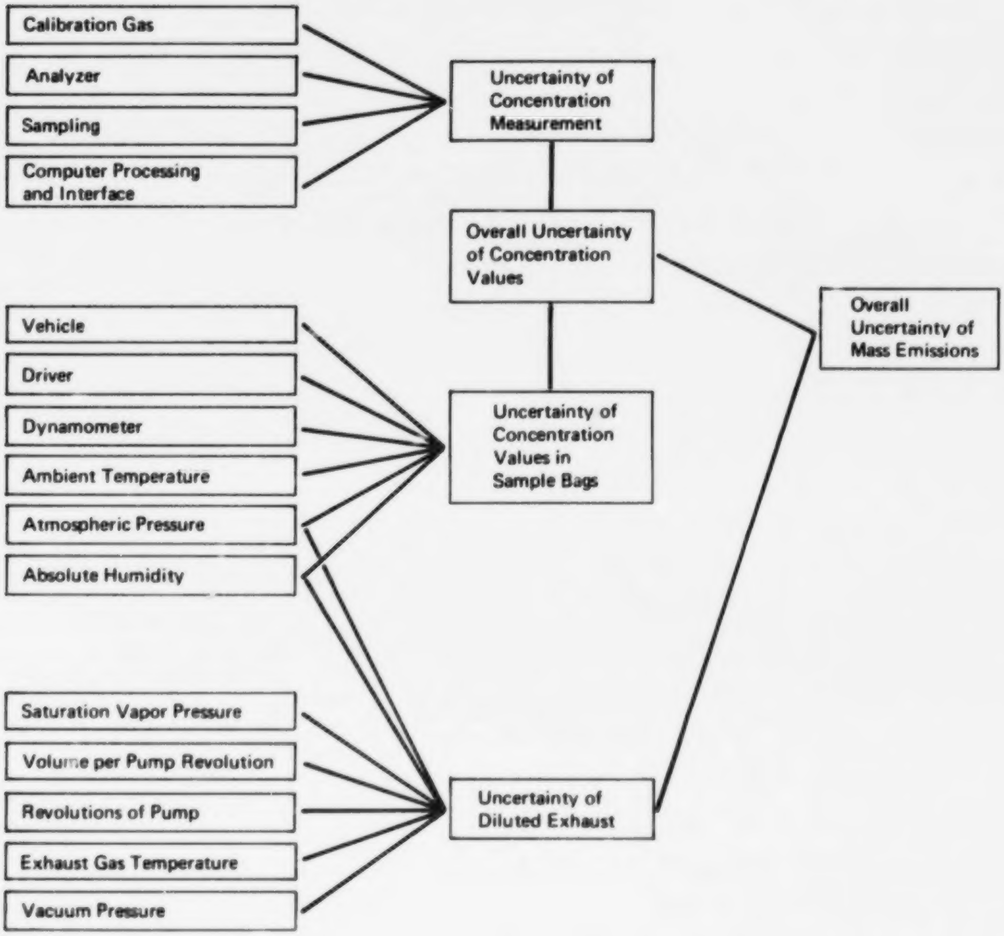
Calibration Gas
Analyzer
Sampling
Computer Processing and Interface
Uncertainty of Concentration Measurement
Overall Uncertainty of Concentration Values
Overall Uncertainty of Mass Emissions
Vehicle
Driver
Dynamometer
Ambient Temperature
Atmospheric Pressure
Absolute Humidity
Uncertainty of Concentration Values in Sample Bags
Saturation Vapor Pressure
Volume per Pump Revolution
Revolutions of Pump
Exhaust Gas Temperature
Vacuum Pressure
Uncertainty of Diluted Exhaust

FIGURE 4.2 Factors Affecting Uncertainty in Exhaust Emission Mass Measurements

REF. 23, 27

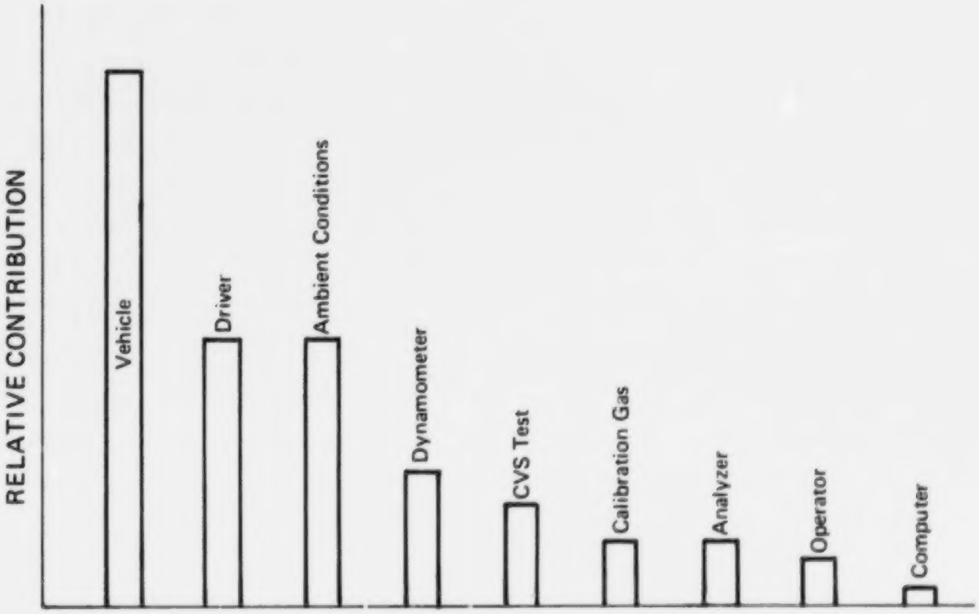

FIGURE 4.3 Sources of Variability and Probable Relative Contribution for Mass Emissions Errors on the CVS-CH Test at 1975-76 California Levels

REF. 23

Three vehicles in the 3,000 lb, 4,500 lb and 5,500 lb inertia-weight classes with HC, CO and NO_x emissions in the range 1.35, 16.5 and 2.4 g/mi, respectively, were employed during the course of the correlation testing. Most of the emission tests were run on a CVS-H cycle in order to minimize vehicle-variability effects on the study. The relative magnitudes of the important sources of variability as reported by the Ford task force are summarized below.

Driver variability, within the specified federal tolerances, was found to significantly affect mass emissions. Based on the average of studies carried out on the three vehicles, it was found that "bad" drivers increased emissions of HC, CO and NO_x by 3.2%, 8.0% and 0.4%, respectively, over results obtained by "good' drivers. The analysis further indicated that the effect of driver skill on emissions is influenced by vehicle inertia weight, dynamometer calibration and driver aid chart speed. As an example, CO increased from 2.5% to 18% on the 3,000-lb and 4,500-lb inertia-weight vehicles, respectively. Results obtained using the controlled measurements showed the increased roll spacing from 17½ in. to 20 in. significantly changed the effect of good to bad drivers on HC and CO emissions at 90% confidence. Dynamometer calibration procedure changes from multiple to single inertia weight also significantly change the effect of good to bad drivers on HC, CO and NO_x emissions at 90% confidence. Furthermore, driver aid chart speed changes from 4 to 6 in./min changes the effect of good to bad drivers on HC and CO emissions at 90% confidence. Thus, these results show that the magnitude of the driver effect on emissions is large but influenced by the vehicle and the equipment at the facility where the tests are conducted.

The study also considered the effects of environmental variables including specific humidity, barometric pressure, vehicle soak-area temperature, test-cell ambient temperature and ambient bag-air concentrations on the variability of exhaust emissions. The effects of specific humidity on CVS-H, HC, CO, CO_2 and NO_x (K_H corrected)* emissions were studied on the three inertia-weight test vehicles. Humidity was an uncontrolled variable ranging from 20 to 66 gr/lb dry air. The experimental results showed that the K_H correction factor for NO_x was not correcting observed emissions such that observed emissions were independent of humidity. Test results showed that the HC and CO emissions increased with increasing humidity for the 3000 and 5000 lb inertia-weight vehicles and had no effect on the 4500 lb inertia-weight vehicle. CO_2 emissions were not affected on any of the test vehicles. These results were reported to be consistent with published reports in that humidity increases HC and CO emissions and effects vary with vehicle calibration.

The effects of barometric pressure on CVS-H emissions of HC, CO, CO_2 and NO_x (K_H corrected) emissions were also estimated. During the studies, barometric pressure was an uncontrolled variable ranging from 28.70 in. Hg to 29.51 in. Hg.

Analysis of results show that increasing barometric pressure by 1 in. Hg decreases average HC and CO emissions 13.6% and 21.0%, respectively, at 90% confidence. NO_x and CO_2 were increased an average of 12.5% and 7.7% at 90% confidence. The effect of barometric pressure on HC, CO, NO_x and CO_2 emissions on the three vehicles varied from -5.7% to -22.5%, -7.2% to -34.9%, -3.5% to 23.2% and 5.5% to 8.1%, respectively.

Due to the nature of the CVS-H test, neither the effect of cell ambinent temperature or vehicle soak-area temperature could be determined. The effect of high ambient air-pollutant concentration (HC_{max} = 10 ppm, CO_{max} = 17.9 ppm, $NO_{x\ max}$ = 2.27 ppm and $CO_{2\ max}$ = 700 ppm) on the variability of exhaust emissions was unknown, but considered to be insignificant.

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* Correction factor presently employed in CVS-CH test method to current NO_x emissions for humidity variations.

The effects of single inertia-weight dynamometer (SIW) calibration versus multiple inertia-weight dynamometer calibration (MIW) and dynamometer roll spacing was also considered in the Ford program. The SIW calibration procedure conforms to the method described in the federal regulations. By this method "...the inertia flywheel for the most common vehicle weight class for which the dynamometer is used" is engaged during the prescribed coast-down procedure. The resulting single calibration curve is thereafter applied to the dynamometer regardless of the actual test inertia condition. For belted-type dynamometers, this procedure is only accurate at the inertia weight at which the dynamometer was calibrated. The MIW is an extension of the SIW wherein a calibration is obtained at each available inertia weight yielding a family of curves for the dynamometer.

The effect of MIW versus SIW dynamometer calibrations was studied for the three test vehicles. Analysis of results show that the single compared to the multiple procedure produced higher HC, CO and NO_x emissions by an average of 2.2%, 0.7% and 1.7%, respectively. The SIW dynamometer calibration indicated that dyno-road-load horsepower at 50 mph was higher for the 5000 lb inertia-weight vehicle and lower for the 3000 lb inertia-weight vehicle than the corresponding loads based on the MIW calibration procedure. The effect of 17½ in. to 20 in. roll spacing at a constant roll diameter of 8.65 in. was also quantified on CVS-H emissions for the three inertia-weight vehicles. This variable was controlled during the experiment by physically changing roll spacing alternately between tests.

Analysis of results showed that the 20 in. roll spacing as compared to 17 in. produced higher HC, CO and NO_x emissions by an average of 3.1%, 2.4% and 0.6%, respectively. Roll spacing had no significant effect on CO_2 emissions. Results also showed that the magnitude of the effect on all emission constitutents was changed by driver skill and by vehicle inertia weight. In addition, roll spacing effects on some of the vehicles were changed by dynamometer calibration procedure and driver's aid resolution.

An analysis of work done (measured at drive shaft) by each vehicle during testing suggests that it may explain the effect of roll spacing changes on emissions. The total work (measured by drive shaft torque) during the CVS-H test using the 10 in. roll spacing versus the 17 in. roll spacing on all inertia-weight vehicles was higher by an average of 1.3%. The largest increase in emissions with the roll spacing change (17¼ in. to 20 in.) was on the medium inertia weight where HC, CO and NO_x increased 3.3%, 4.5% and 2.8%, respectively, and where total work increased 2.4%. On the small inertia-weight vehicle, however, changing the roll spacing from 17¼ in. to 20 in. caused CO emissions to decrease 3.2%. From these results, it can be concluded that all engine calibrations do not react the same to increased dynamometer loading.

During the Ford correlation program, the combined CVS sampling and gas analytical systems were evaluated by means of a very precisely regulated vehicle gas simulator once each day of vehicle testing. The data from these studies showed that although measurement variability for any one facility may be within acceptable limits, systematic differences in these systems may exist between facilities of magnitudes ranging from 2.2% to 8.0%.

General Motors Corporation[23] reported the results of 18 CVS-CH tests, carried out in an environmental chamber, designed to evaluate the sensitivity of exhaust emissions to barometric pressure and humidity variations. The test vehicle was equipped with a 350 CID engine, EGR, and early fuel evaporation manifold, integrated fuel control with altitude compensation and dual-mode emission-control system. All tests were carried out with the same driver and three levels of ambient pressure ranging from 26 in. Hg to 30 in. Hg and three values of humidity ranging from 30 to 100 gr/lb dry air were studied. The results of this study based on a linear regression analysis are listed in Table 4.10. Inspection of these results indicates that a one-inch increase of barometric pressure resulted in reduced HC and CO emissions of 10% and 30%, respectively, and an increase of NO_x and

TABLE 4.10

Effect of Barometric Pressure and Humidity on Exhaust Emissions of a Vehicle

Source	Percent Change			
	HC	CO	NO_x	CO_2
One In Hg Increase in Barometric Pressure				
GM Environmental Chamber Data	-10	-30	+5	+2.2
Ford Data Based on Multiple Regression Analysis of Three Vehicles	-13.6	-21	+12.5	+7.7
50 Grains Increase in Absolute Humidity				
GM Environmental Chamber Data	+10	+25	---	-1.5

REF. 23, 29

CO_2 of 5% and 2.2%, respectively. An increase in the absolute humidity of the air by 50 gr/lb resulted in a 10% and 25% increase of HC and CO emissions, respectively, had no apparent effect on NO_x (results computed taking K_H correction factor into account) and resulted in a 1.5% decrease in CO_2. During the course of these tests, CO emissions were in the range of approximately 1.5 to 5.0 g/mi. Data relating the effect of cell-ambient temperature on exhaust emissions were not reported.

The data averaged over three vehicles, previously reported by Ford,[29] detailing the effect of ambient pressure on exhaust emissions are also listed in Table 4.10. The GM and Ford data relating barometric pressure effects on emissions are in reasonable agreement. Ford[29] also reported that both HC and CO increased with increasing humidity for two of the three vehicles tested and that the third vehicle's HC and CO emissions were not affected by humidity. In contrast to the GM data, the Ford data indicated that the NO_x humidity correction factor (K_H) did not adequately account for variation of NO_x with humidity. Ford reported that humidity changes did not affect CO_2 emissions while GM reports a slight decrease in CO_2 as the humidity increases.

The California Air Resources Board[30] reported the results of a study designed to determine the dependence of exhaust emissions on vehicle cold-soak temperature, encompassing the range allowed in the federal test procedure prior to initiation of the CVS-C test. Six 1973 vehicles from various foreign and U.S. manufacturers were studied and the averages for HC, CO and NO_x at 60, 73 and 86°F cold-soak temperatures are shown in Table 4.11. These data indicate a trend of decreasing HC and CO emissions with increasing cold-soak temperature, which might be expected due to shorter warm-up time at higher temperature. The result of little variation in NO_x emissions with soak temperature is also expected.

The CVS sample collection method involves dilution of the exhaust gases by approximately a factor of 10. This factor when combined with

TABLE 4.11

Average Emissions for Six 1973 Vehicles as a Function of Cold Soak Temperature

Soak Temperat re (°F)	HC (g/mi)	CO (g/mi)	NO_x (g/mi)
60	2.16	26.23	2.80
73	2.12	25.40	2.78
86	1.84	21.20	2.78

REF. 30

the low-emission standards and the necessity of subtracting the concentration of the pollutants simultaneously collected in a background sample bag from the measured emissions may cause both systematic and random errors in the measurement of pollutants collected during an emissions test. Typical sample-bag concentrations of pollutants for vehicles meeting the 1975 interim California standards and the 1978 Federal standards are listed in Table 4.12. Instrument sensitivity may cause problems at the 1978 Federal levels.

The preparation, stability and labeling of calibration gases at the levels required for exhaust-emission measurements has accounted for significant random errors in the past. In order to provide a mechanism for developing comparisons of the accuracy and repeatability of gas analysis procedures utilized at various laboratories, the Scott Calibration Gas Cross-Reference Service has been developed.

At the present time, there are four services available, including Automotive Exhaust, Diesel Exhaust, Nitric Oxide and Constant Volume Sampling. Four times a year, analytical laboratories who subscribe to one or more of the services receive gas cylinders of unknown gas mixture. The components are specified, but their concentrations are unknown. Each participating laboratory analyzes the mixture and reports their results to a coordinator. Subsequently, each participating laboratory receives a detailed report listing results from all participants and providing a statistical analysis of the results. The results of a recently published CVS Cross-Reference Service[31] are summarized for HC, CO and CO_2 in Table 4.13. The unknown samples of HC in air, CO in air and CO_2 in air were analyzed for HC as ppm propane with FID's and both the CO and CO_2 were determined with NDIR analyzers. The results of a recent Scott Nitric Oxide Cross-Reference Service[32] are also listed in Table 4.13. The NO data were obtained with chemiluninescence detectors.

In an effort to reduce systematic errors associated with calibration gases, the National Bureau of Standards (NBS) has recently agreed

TABLE 4.12

Typical Pollutant Concentrations in Exhaust Emissions Sample Bags at Various Emission Levels

1975 California Standards	HC	CO	NO_x
Standards, g/mi	0.9	9	2.0
Sample bags, ppm			
cold transient	40	600	90
stabilized	18	200	40
hot transient	33	341	90
Typical Ambient Background Concentrations, ppm	5	8	1
1978 Standards			
Standards, g/mi	0.41	3.4	0.4
Sample Bags, ppm			
cold transient	22	133	9
stabilized	6	6	4
hot transient	9	12	9
Typical Ambient Background Concentrations, ppm	5	8	1

REF. 12, 29

TABLE 4.13

Measurement of the Concentration of Pollutants in an Unknown Sample at Many Laboratories

	HC (ppm, propane)	CO (ppm)	CO_2 (%)	NO (ppm)
No. of Data	12	18	17	26
Average, $\bar{x}$	100.85	1163	1.44	158.6
Median	100.80	1166.5	1.44	157.5
Range	98.0 - 103.7	1100 - 1203	1.35 - 1.50	140.75 - 180.0
Estimate of Standard Deviations	1.78	24.84	0.04	8.48
$s/\bar{x}$, %	1.8	2.1	2.8	5.3

REF. 31, 32

to develop a set of master calibration gas standards with accuracy within ±1% of the specified cylinder value. The proposed NBS standard calibration gases are listed in Table 4.14. At the present time, the C_3H_8 in air, CO in N_2 and CO_2 in N_2 have been produced, and the NO in N_2 standards are projected to be available in September 1974. A meeting was held at NBS in May 1974 to discuss user experiences with the prepared standards. In general, there appeared to be agreement among all government and industry participants that the NBS standards were within the specified ±1% tolerance levels, except possibly for the nominal 10 ppm C_3H_8 in air standard. Additional work with this mixture is being undertaken.

In many instances, a significant fraction of the total mass of both HC and CO collected during the CVS-CH test is collected in the cold transient phase of the test and, hence, in these cases, the cold-start weighting factor in the test method plays a significant role in the technological demand placed on a control system. The results listed in Table 4.2[22] indicate that the cold transient phase of the CVS-CH test accounted for approximately 52% and 59% of the total mass of HC and CO collected during the 30 tests on a specific 1971 vehicle. In these tests, the variability of the HC and CO collected in the cold transient phase of the test was also reported to be greater than the variability associated with the other two phases of the test.

The mass of HC and CO collected during each phase of the CVS-CH test for seven production vehicles ranging from the 1967 to the 1973 model year has also been reported.[33] In these tests, which were carried out at an ambient temperature of 75°F, the cold transient phase of the test accounted for approximately 35% to 51% and 39% to 77% of the mass of the HC and CO collected during the total test, respectively.

Due to thermal effects, it has been suggested that the cold transient phase may account for an even greater fraction of the total HC and CO emissions when oxidation catalysts are employed on

TABLE 4.14

National Bureau
of Standards Calibration
Gas Standards

C_3H_8 in Air	CO in N_2	NO in N_2	CO_2 in N_2
Nominal Value (ppm)	Nominal Value (ppm)	Nominal Value (ppm)	Nominal Value (%)
3	10	25	1
10	50	50	7
50	100	100	14
100	500	250	
500	1000	500	
		1000	

REF. 59

vehicles.[12] The data listed in Table 4.3 indicate that the cold transient phase of the CVS-CH test accounted for 87% and 94% of the total mass of HC and CO, respectively, for a vehicle equipped with an oxidation catalyst.[23] In addition, these data indicate that the variation in HC and CO during the cold transient phase accounted for 99% of the total variation in HC and CO during the CVS-CH test.

Data reported by Reference 33 can also be employed to investigate the effect of ambient temperature on the total mass of HC, CO and NO_x produced during each of the three phases of the CVS-CH test for four prototype 1975 vehicles equipped with oxidation catalysts. At an ambient temperature of 75°F, the average value, taken over all four vehicles, of the total mass of HC and CO collected in the cold transient bag accounted for approximately 64% and 73% by mass of the pollutants collected in the three bags, respectively. Under these conditions, the average composite CVS-CH emissions for these vehicles were 0.49, 5.5 and 2.32 g/mi for HC, CO and NO_x, respectively.

In addition to the composite emissions presented in Table 4.5, modal emission data are also available for the vehicles equipped with 2.0 liter CVCC stratified-charge engines.[25] In these vehicles, the cold transient phase account for approximately 50% to 60% and 30% to 40% of the total mass of HC and CO collected during the CVS-CH test, respectively.

In the present CVS-CH test procedure,the total mass of pollutant emissions in the cold transient, hot transient and stabilized portions of the test are weighted by 0.43, 0.57 and 1.0, respectively. Therefore, the contribution of the cold transient phase to the computed vehicular composite emissions in grams per mile is not only dependent on the total mass of pollutant collected but also on the weighting factors.

4.5 Effect of Ambient Temperature on Exhaust Emissions

It has been previously reported that exhaust emissions[12] on the CVS-C test for vehicles soaked at either 20°F or 40°F were significantly greater for both vehicles, with and without oxidation catalysts, than the emissions for the same vehicles when they were soaked in accordance with the CVS-CH test (e.g., 60°F to 86°F). The Emission Testing Laboratory of Environment Canada studied the effect of ambient temperature on exhaust emissions.[34] The test procedure used during the course of the tests was very similar to the CVS-C test procedure, and tests were conducted on five 1972 and 1973 vehicles. Each vehicle was tested 30 to 40 times under cold conditions and 15 to 20 times under baseline conditions (e.g., 60°F-86°F).

Linear correlations of present emission changes as referenced to emissions measured at 60°F were found to correlate the data better than parabolic fits. The average of the emissions from the five vehicles tested for HC and CO are plotted in Figure 4.4 as a function of percent deviation from the average emissions at 60°F. The average HC curve yields a 100% increase in HC emissions at 8°F as compared to the 60°F emissions. The correlation lines for all five vehicles had different slopes ranging from approximately 0.62 to 1.5 times the average slope. The CO average curve yields an increase of 100% in CO emissions at 20°F as compared to the 60°F emissions. The slopes of the lines for the five cars were all different with slopes ranging from approximately 0.3 to 1.6 times the average slope. The average NO_x emissions from the five vehicles showed a slight decrease in emissions (less than 3%) at 0°F as compared to emissions at 60°F.

The Bartlesville Energy Research Center of the U.S. Department of Interior has recently completed a series of tests designed to determine the effect of ambient temperature on exhaust emissions and fuel economy for twenty production cars from 1967-1973, four prototype 1975 emission cars with oxidation catalysts, one vehicle equipped with a diesel engine and one vehicle equipped with a PROCO-type stratified-charge engine.[33]

The experiments were carried out using the CVS-CH test procedure and the results are summarized in Table 4.15. The effect of ambient

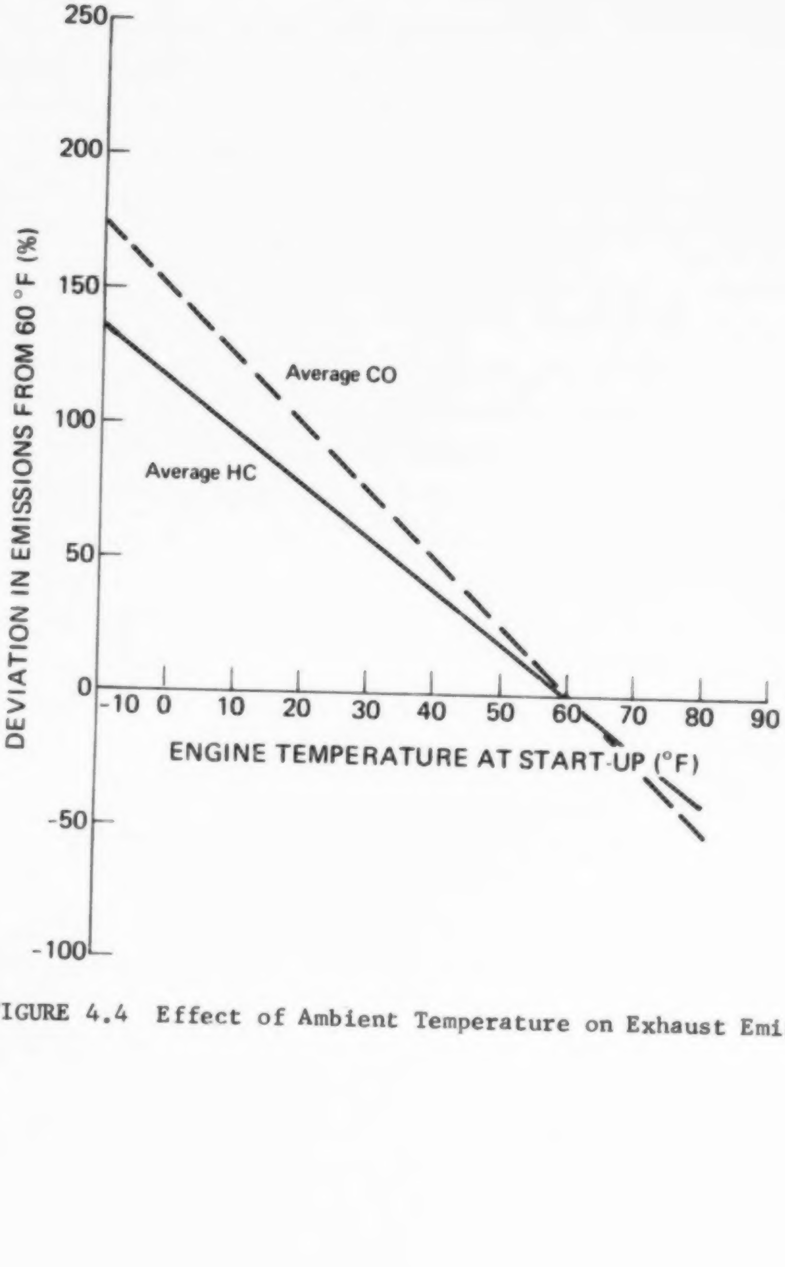

FIGURE 4.4 Effect of Ambient Temperature on Exhaust Emissions

REF. 34

TABLE 4.15

Effect of Ambient Temperature on Exhaust Emissions of Various Vehicles on the CVS-CH Test

	Test Temperature, °F				Tests with and without Air Cond., 110° F 2/	
	20	50 1/	75	110	With	Without
Production vehicles 3/						
Hydrocarbon	7.44	5.63	4.66	4.67	4.56	3.98
Carbon monoxide	81.6	65.4	53.8	63.5	72.3	57.8
Nitrogen oxides	6.40	5.25	5.06	4.13	5.94	4.44
Aldehydes	.23	.20	.18	.17	.11	.14
Hydrocarbon 4/						
Total	8.51	5.90	5.01	4.95	4.28	3.61
Non-methane	7.76	5.44	4.71	4.67	3.98	3.35
Reactive	6.55	4.70	4.01	4.33	3.33	2.80
Fuel economy, mpg	10.8	10.9	11.4	11.5	10.34	11.58
Catalyst equipped 5/						
Hydrocarbon	1.31	.81	.49	.50	.54	.50
Carbon monoxide	28.0	15.8	5.5	6.1	11.9	6.1
Nitrogen oxides	3.14	3.05	2.33	2.35	2.66	2.35
Aldehydes	.035	.035	.040	.021	.010	.020
Hydrocarbon 4/						
Total	1.31	.81	.49	.50	.52	.49
Non-methane	1.03	.66	.40	.38	.40	.38
Reactive	.90	.57	.35	.34	.35	.33
Fuel economy, mpg	9.6	10.3	10.8	11.4	10.2	11.4
Stratified charge, PROCO 6/						
Hydrocarbon	.55	.28	.20	.14	-	-
Carbon monoxide	1.8	.6	.7	.4	-	-
Nitrogen oxides	1.37	1.25	1.05	1.07	-	-
Aldehydes	.04	.03	.01	.01	-	-
Hydrocarbon						
Total	.55	.28	.20	.14	-	-
Non-methane	.46	.22	.15	.11	-	-
Reactive	.40	.20	.13	.10	-	-
Fuel economy, mpg	19.3	20.4	21.2	20.5	-	-
Diesel equipped 6/						
Hydrocarbon	.60	.30	.49	.40	-	-
Carbon monoxide	1.9	1.4	1.4	1.2	-	-
Nitrogen oxides	2.06	1.99	1.78	1.88	-	-
Aldehydes	.05	.04	.05	.05	-	-
Fuel economy, mpg	17.1	18.6	19.7	20.1	-	-

1/ Five 1973 vehicles not tested at 50° F.
2/ Thirteen production cars.
3/ Twenty cars--duplicate tests.
4/ Six cars.
5/ Four cars--duplicate tests.
6/ Single car--duplicate tests.

REF. 33

temperature on HC, CO and NO_x exhaust emissions for the various types of vehicles tested are graphically represented in Figures 4.5 to 4.7. Inspection of these results indicates that ambient temperature has a significant effect on HC and CO emissions for the twenty 1967-1973 production vehicles. Hydrocarbon and CO emissions increase by 60% and 52%, respectively, when the vehicles were tested at 20°F in comparison to tests at 75°F. The NO_x emissions from the same group of vehicles increased by approximately 25% in the same temperature interval.

The HC and CO emissions from the four prototype, catalyst-equipped vehicles increased by 160% and 409%, respectively, when the tests were carried out at 20°F rather than 75°F. The NO_x emissions for these same vehicles increased by approximately 33% over the same temperature interval.

Hydrocarbon emissions for the diesel and stratified-charge PROCO-powered vehicle were also found to increase significantly between 75°F and 20°F. In contrast, the CO emissions from these two vehicles were relatively constant with ambient temperature. NO_x emissions for these two vehicles were also shown to be less dependent on ambient temperature than the emissions from either class of spark-ignition, engine-powered vehicles.

As indicated earlier, the cold transient phase of the test accounted for approximately 64% and 73% of the total mass of HC and CO, respectively, for the four prototype, catalyst-equipped vehicles when the test was run at 75°F. At 20°F, the cold transient phase accounted for approximately 89% and 96% of the total HC and CO collected for the same vehicles.

4.6 Durability Test Methods and Procedures

The test methods and procedures associated with the development of emission-deterioration factors (DF) for the durability-data fleet have been discussed in Section 4.2. Some concerns have been raised

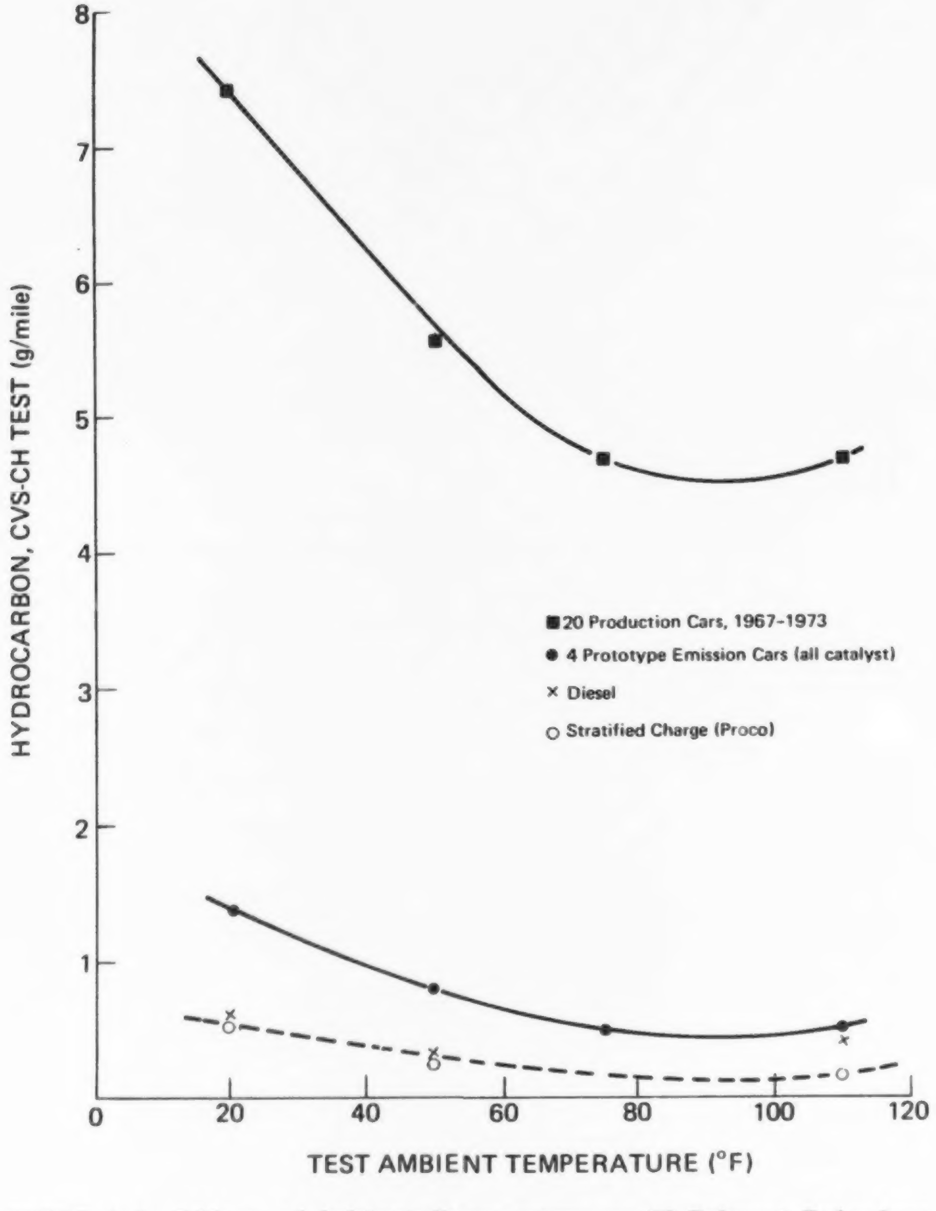

FIGURE 4.5 Effect of Ambient Temperature on HC Exhaust Emissions During the CVS-CH Test

REF. 33

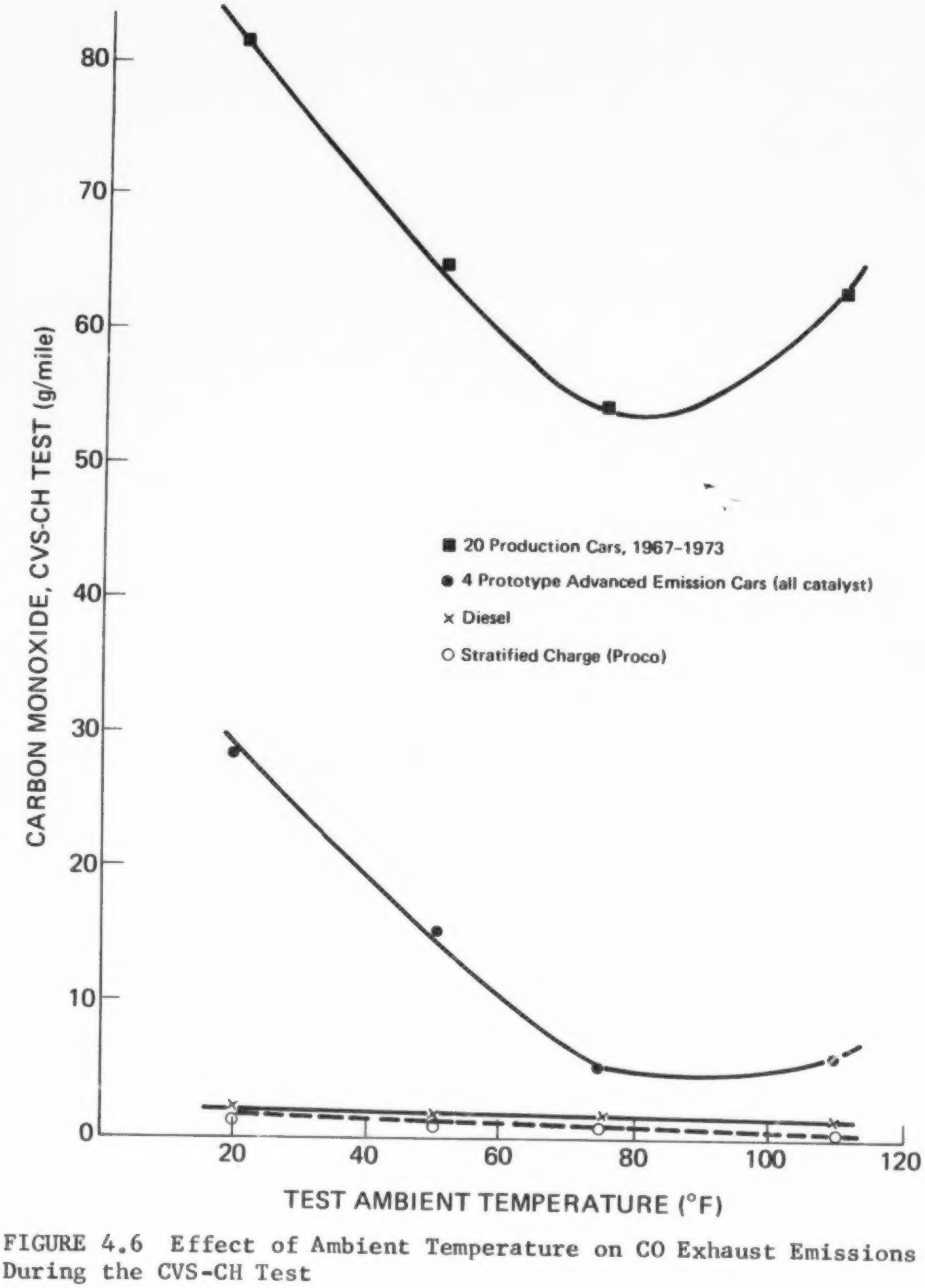

FIGURE 4.6 Effect of Ambient Temperature on CO Exhaust Emissions During the CVS-CH Test

REF. 33

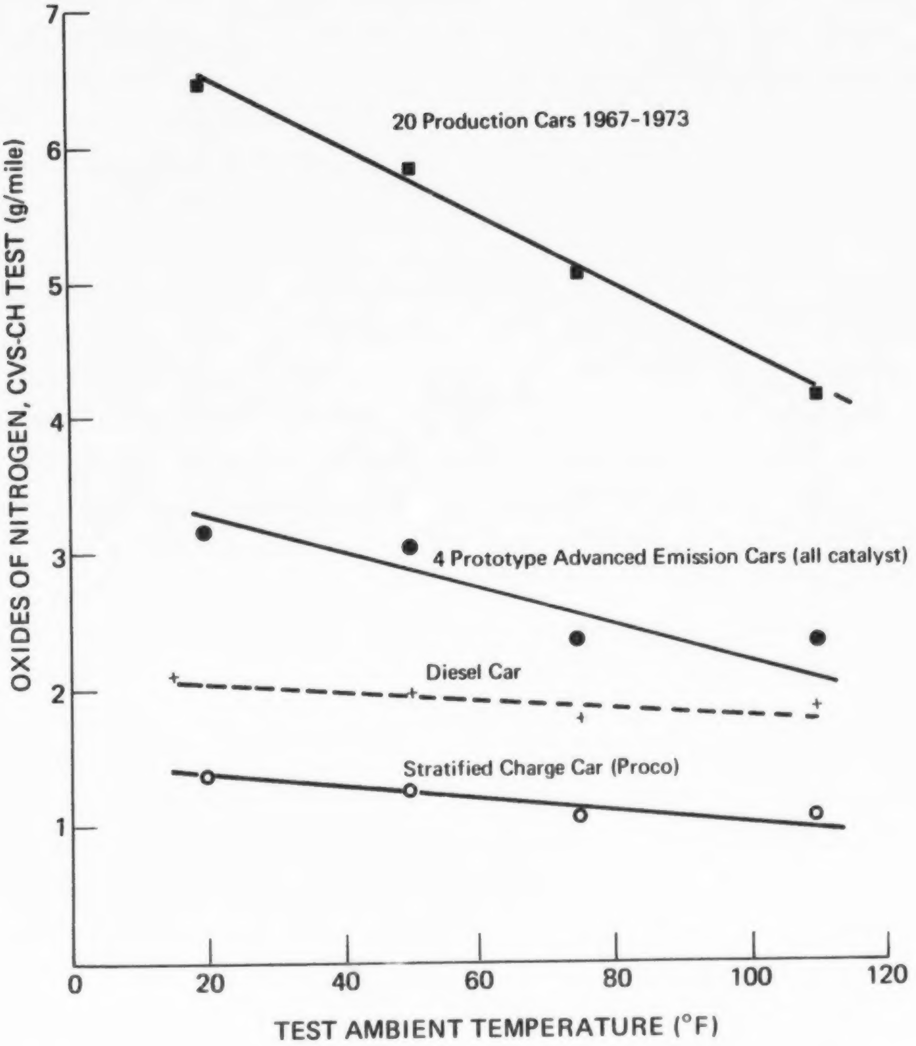

FIGURE 4.7 Effect of Ambient Temperature on NO_x Emissions During the CVS-CH Test

REF. 33

over the methods that are presently employed to determine the deterioration factors which are subsequently used in certification. It has been suggested that statistical variability associated with exhaust-emission tests may cause errors in the determination of deterioration factors when only a limited number of durability-data cars are tested for a particular engine-system combination.[56,57] In addition, concern has been raised over the ratio method that is presently employed to obtain the deterioration factors for durability-data vehicles.[35] Both of these points are discussed below.

Monte Carlo Simulation techniques have been used[57] to generate statistically possible emission test measurements at 5,000 mile increments in order to estimate the effect of test-error variability on calculated deterioration factors. In this simulation, fleets of 10, 30 and 50 durability-data vehicles with various mean emission values, specified deterioration factors and test-to-test variability were hypothesized. Test-point measurements for each vehicle in the fleet were computed using the test variability for 5,000 through 50,000 miles of simulated durability mileage accumulation. Subsequently, a least-square regression line was fitted through each set of simulated data and a DF was calculated for each vehicle.

Typical results based on the Monte Carlo Simulation computations for a fleet of 10 identical vehicles indicating the possible variability in the DF as a function of exhaust-emission, test-to-test variability are listed in Table 4.15a.[57] Inspection of these results indicates that the mean value of DF for the 10-vehicle fleet is in reasonable agreement with the true value of DF as a function of both the exhaust emissions at 4,000 miles and the test-to-test coefficient of variation. However, the coefficient of variation of the DF's computed for each 10-vehicle fleet are generally approximately equal to the corresponding test-to-test coefficient of variation.

Another Monte Carlo Simulation which included deterioration-factor variability as well as car-to-car and test-to-test variability has been reported by Reference 58. The necessary input in this simulation included a 50,000 mile emission point, an absolute deterioration factor, and absolute values of the test-to-test, car-to-car and

TABLE 4.15a

Monte Carlo Simulation of Possible Variability in DF
as a Function of Test-to-Test Variability

EMISSIONS AT 4,000 MI (g/mi)	TRUE DF = 1.0						TRUE DF = 2.0					
	COV = 10%		COV = 20%		COV = 30%		COV = 10%		COV = 20%		COV = 30%	
	$\overline{DF}$	$\frac{s}{\bar{x}}$ %	$\overline{DF}$	$\frac{s}{\bar{x}}$ %	$\overline{DF}$	$\frac{s}{\bar{x}}$ %	$\overline{DF}$	$\frac{s}{\bar{x}}$ %	$\overline{DF}$	$\frac{s}{\bar{x}}$ %	$\overline{DF}$	$\frac{s}{\bar{x}}$ %
.41	.978	8	1.00	15	1.20	37	2.11	9	2.12	39	2.36	50
1.5	.931	9	1.05	22	.966	32	2.02	6	1.99	26	2.19	48
3.1	.949	12	.980	19	1.05	24	2.06	11	2.29	29	1.99	22
9.0	1.03	12	.986	17	1.13	24	2.03	9	1.97	21	2.22	34
15	.983	11	.998	19	..901	23	1.99	11	2.24	16	1.70	20

Fleet Size = 10

COV = test-to-test coefficient of variation, %

$\frac{s}{\bar{x}}$ % = deterioration factor coefficient of variation % from Monte Carlo Simulation

$\overline{DF}$ = mean deterioration factor from Monte Carlo Simulation

REF. 57

deterioration-factor variability. These values were used to randomly adjust 5,000 mile increment emission-data points in order to calculate statistically possible deterioration factors, 50,000 mile and 4,000 mile intercepts. The results were analzed to obtain the probability that an emission test would yield adjusted emissions below the federal standards given a deterioration factor and a 50,000 mile emission value. Also determined was the adjusted emission value below which 95% of all adjusted emissions could be expected to lie. These computations indicated that the various sources of variability contribute to the probability that a given vehicle will pass an emission test. Further discussion of the technique used and a complete table of the results obtained may be found in Reference 58.

The Monte Carlo Simulation reported in Reference 57 indicates that statistical variability associated with the determination of DF's may reflect the special circumstances of the test rather than the capability of the underlying technology. This idea is particularly relevant when it is realized that deterioration factors are often based on emission tests of a single durability-data car. In order to reduce these errors, some type of data-averaging procedure over a larger group of "similar vehicles" might be preferable for deterioration-factor calculations. However, a too-extensive use of average treats all vehicles and systems as equal and, hence, attractive technologies may be counterbalanced by less desirable technologies. At the present time, the manufacturer has the option of testing more than on "identical durability-data vehicle" in each engine-system combination, with all the emission data collected being used to calculate the deterioration factor. If appropriate allowances could be made for possible malfunction of a durability-data car in a small fleet of "identical vehicles," a data-averaging technique would be statistically desirable but still might not be cost-effective from the manufacturer's point of view.

It has also been suggested that the ratio method presently employed to compute DF based on the durability data may unnecessarily penalize durability vehicles with relatively low 4,000 mile extrapolated emissions.[35]

As described previously, a deterioration factor (DF) for each pollutant is determined by fitting a least squares best fit straight line to all durability emission data and defining DF in terms of

$$(DF)_i = \frac{\text{exhaust emissions of pollutant } i \text{ at } 50{,}000 \text{ miles}}{\text{exhaust emissions of pollutant } i \text{ at } 4{,}000 \text{ miles}} \qquad (1)$$

where the exhaust emissions at both 4,000 miles and 50,000 miles are obtained from the least squares fit line. To facilitate discussion and introduce appropriate nomenclature, a least-squares line representing a "typical" deterioration-factor test result is shown in Figure 4.8. The least-squares line obtained from the data is represented by $E(x) = m\,x + b$; where $E(x)$ is the emissions at x miles and m and b are the least mean square values of the slope and intercept, respectively. The equation for the least squares line can be readily rewritten in terms of the slope m and the interpolated value of the emissions at 4,000 miles (I).

$$E(x) = m\,(x-4{,}000) + I \qquad (2)$$

The deterioration factor as computed by EPA for the data in Figure 4.8 would be given by

$$DF = \frac{E(50{,}000)}{E(4{,}000)} = \frac{m(50{,}000 - 4{,}000) + I}{I} \qquad (3)$$

or simplifying

$$DF = 1 + \frac{46{,}000\ m}{I} \qquad (4)$$

Inspection of Equation (4) indicates that the DF, as computed by EPA, is dependent on both the slope of the deterioration line and the extrapolated value of the line at 4,000 miles.

The vehicle under consideration is checked for certification by testing a corresponding emission-data car at 4,000 miles and multiplying the numerical value (X) of each pollutant measured during this test by the DF.

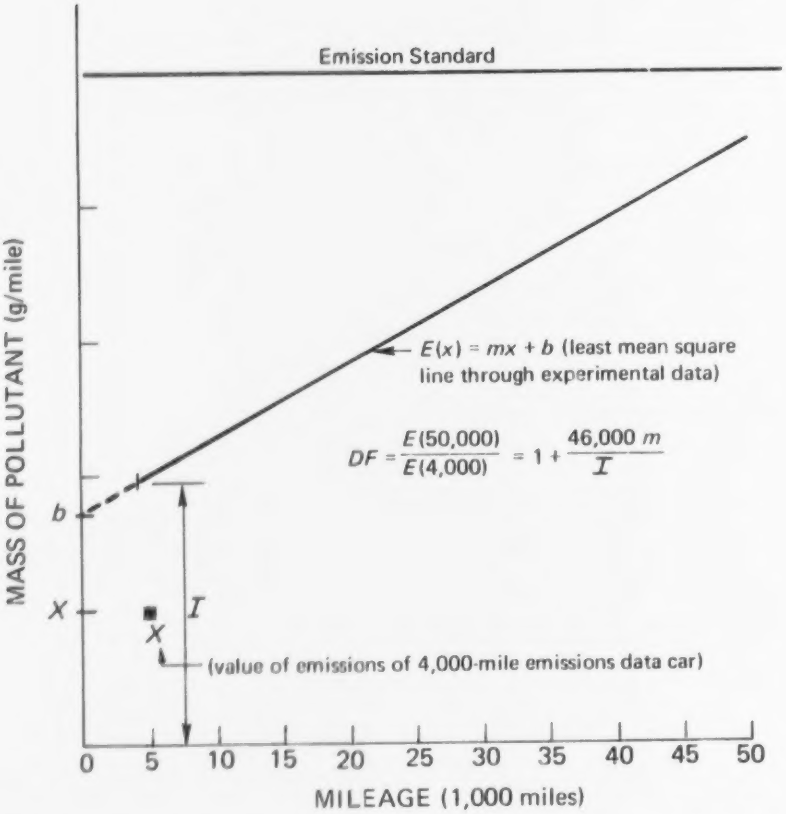

FIGURE 4.8 Alternate Methods for Evaluating the Deterioration of Emission Control Systems

$$\text{Certification value} = DF \times X = \left(1 + \frac{46{,}000\ m}{I}\right) X. \tag{5}$$

If the certification value, as computed from Equation (5), is less than the appropriate standard, the vehicle passes; if not, it fails.

If one assumes that the rate of deterioration of the emission-control system is not a function of either the extrapolated value of the emissions at 4,000 miles (e.g., $m \neq m\ (I)$) for the durability-data vehicle or the calibration of the system, then this technique, as outlined in Equation (5), may unnecessarily penalize an emission-data car whose corresponding durability-data car had a low value of extrapolated emissions at 4,000 miles (I).

In order to circumvent this potential problem, Hromi[35] has suggested another method for determining whether a vehicle passes certification. This technique is based on a simple difference formulation as given by Equation (6):

$$\begin{aligned} \text{Certification Value} &= X + E(50{,}000) - E(4{,}000) \\ &= X + 46{,}000\ m \end{aligned} \tag{6}$$

The vehicle would pass if the certification value, as computed from Equation (6), was less than the appropriate emission standard and fail if it was greater than the standard.

Sufficient data could not be obtained during the course of this study to determine if $m \neq m(I)$ for various control systems, durability-car calibrations, etc. If at a later date sufficient data are available for a range of emission-control systems, it might be appropriate to consider changing the method of combining durability data with emission standards as outlined by Equation (6) rather than the method presently employed (Equation 5).

4.7 Evaporative HC Emissions

In addition to HC exhaust emissions discussed previously, fuel evaporation losses may contribute significantly to the total HC emissions from LDMV. Evaporative emissions differ from exhaust emissions in that evaporative emissions are formed as a result of physical rather than chemical processes. In general, fuel hydrocarbon can be emitted as a result of the evaporation process from both the fuel tank and the carburetion system. A motor vehicle experiences evaporative hydrocarbon emission as a result of its normal operating procedure. For example, at the end of every vehicle trip, evaporation may occur from the carburetor bowl due to heat being transferred from the engine block. The evaporated vapor may then escape through any available opening in the carburetor system. This type of hydrocarbon evaporation is known as "hot soak losses." Other evaporative losses have been termed "diurnal," "running," and "refueling" losses. The diurnal loss is the result of the daily temperature rise and the corresponding evaporation of hydrocarbon fuel from the fuel tank. Running losses are similar to both the diurnal and hot-soak losses except that the necessary temperature increase and heat transfer are provided by the engine when it is operating. Refueling losses occur whenever fuel vapors are emitted during fueling operations.

A test method has been developed to measure diurnal, running and hot-soak evaporative emissions. Prior to initiating the test, the vehicle is soaked for at least 12 hours to insure that the engine has completely cooled down. Cool fuel is placed in the tank and the diurnal losses are collected by heating the fuel from 60°F to 84°F in one hour. The vehicle is subsequently run on the CVS-CH cycle and the engine is shut down. The running and hot-soak emissions are collected during the test cycle and the one-hour period following engine shutdown. The HC emissions collected during this test can be subsequently utilized to estimate the grams of HC evaporated per day from the fuel tank (diurnal losses) and the grams of HC evaporated from the system during an average urban trip and the one-hour period subsequent to engine shutdown (running plus hot-soak losses). The present federal standard for evarporative emissions is 2.0 g/test.

In order to compare the magnitude of exhaust and evaporative HC emissions, it is necessary to develop a formula that can be utilized to convert evaporative test results to g/mi. Reference 36 has suggested that an appropriate expression for converting evaporative-emission results to g/mi is given by:

$$\left(\begin{array}{l}\text{evaporative HC emissions}\\ \text{in g/mi}\end{array}\right) = \left(\begin{array}{l}\text{dirunal losses}\\ \text{in g/test}\end{array}\right) \Big/ \left(\text{miles per day}\right) + \left(\begin{array}{l}\text{running and hot-soak losses}\\ \text{in g/test}\end{array}\right) \Big/ (\text{miles per trip}) \tag{7}$$

Suitable average values of miles per day and miles per trip are 34 and 7.5, respectively.

Two different methods have been developed for collecting and measuring evaporative HC emissions. Presently, the method used by the federal government for certification of evaporative emission-control systems[20] is based on measuring the weight of fuel vapor absorbed in carbon canister traps. The traps are connected to the fuel tank vents and to the carburetor external vent during the course of the test. After the test is completed, the traps are disconnected from the vehicle and weighted to determine if the 2.0 g/test standard is met. The second test method, the Sealed Housing for Evaporative Determinations (SHED) method,[37] is more comprehensive. Basically, the SHED method involves placing the vehicle in a sealed enclosure throughout the test, and the HC concentration in the enclosure at the end of the test, measured with an FID, is used to determine the mass of HC evaporative emissions. Further discussion of the SHED method may be found in References 38 and 39.

A study[40] employing the SHED method to determine HC evaporative emissions reported that average evaporative HC emissions for 55 preevaporative-controlled vehicles was about 37 g/test. Based on these results, it has been estimated that evaporative emissions from precontrolled vehicles (i.e., pre-1971 model-year vehicles) were approximately 3 g/mi.[41]

The results of evaporative-emission certification tests for model years 1971-1974, based on the carbon canister trap method, are shown in Table 4.16.[42] It was shown that 60% of the tests reported as less than 0.1 g were actually reported as 0.0 g, and that in general, most of the tests reported as 0.0 g corresponded to negative canister-weight changes. Comparison of the evaporative-emissions data shown in Table 4.16 with the estimated precontrolled evaporative emissions of 37 g/test seems to indicate that present evaporative-control systems are very effective, and that evaporative emissions have been essentially completely controlled.

The evaporative HC emissions results obtained in two recent EPA surveillance programs[42,43] for both precontrolled and controlled evaporative-emissions systems indicate that this conclusion is not correct. The surveillance program carried out in 1972 measured evaporative emissions from both controlled and uncontrolled vehicles employing the SHED method.[43] The SHED method was employed during these tests rather than the carbon-canister-trap method since it takes into account evaporative emissions from the entire fuel system including gasket and throttel shaft leakages. In addition, vehicles manufactured prior to the implementation of evaporative controls are not readily amenable to measurement by the carbon-canister method. Evaporative-emission measurements were made in Los Angeles for 136 vehicles ranging from 1957 to 1971 model year and twenty-two 1971 model-year vehicles were tested in Denver to assess the effect of high altitude. The results of these tests are summarized in Table 4.17. The weighted values of these HC emissions in grams per mile as computed from Equation (7) are also listed in Table 4.17. Results from the 1972 fiscal year surveillance program included evaporative-emission tests on twenty-two 1972 model-year vehicles in both Los Angeles and Denver. These results were also based on the SHED method and the data as reported in Reference 42 are also listed in Table 4.17.

Inspection of these results indicates that the weighted value of the uncontrolled vehicles of 2.7 g/mi is in good agreement with the previously estimated value of 3.0 g/mi. The significant difference in

TABLE 4.16

Summary of Evaporative HC Emission Test Results for 1971-1974 Certification Test Results[1]

MODEL YEAR	NO. OF TESTS	PERCENT OF TESTS LESS THAN 0.1 g	PERCENT OF TESTS LESS THAN 1.0 g	MAX. VALUE (g/test)	AVERAGE VALUE (g/test)	FED. STD. (g/test)
71	131	32	82	3.65	0.545	6.0
72	370	45	91	1.90	0.307	2.0
73	351	56	94	1.90	0.251	2.0
74	399	45	98	1.90	0.258	2.0

[1] Test based on carbon canister trap method

REF. 42

TABLE 4.17

Summary of Evaporative HC Emission Test Results Obtained During Surveillance Tests[1]

		L. A. Data (g)		Denver Data (g)		Weighted Values
Model Year	No. Tests	Diurnal	Hot Soak	Diurnal	Hot Soak	g/mi
57-69	102	26.08	14.67	-	-	2.7
70	13	17.75	10.70	-	-	1.9
71	21	14.87	10.89	-	-	1.9
71	22	-	-	47.2*	34.8*	6.0*
72	22	12.40	11.80	-	-	1.9
72	22	-	-	17.4	14.2	2.4

Note: *Winter grade fuel (11.7 RVP) used on all tests. L.A. data up to 1971 used all types of fuel (7.8 - 12.0 RVP).

[1] Experimental data based on SHED method

REF. 42, 43

the 1971 and 1972 model-year evaporative emissions obtained in Denver has been attributed to the differences in fuel volatility that were employed during the testing. The 1971 Denver vehicles were tested using commercial winter-grade fuel of high volatility (RVP = 11.7 psi), and the 1972 vehicles were tested using the standard test fuel of summer-grade volatility (RVP = 8.8 psi). Significantly higher evaporative emissions are to be expected when testing with high-volatility fuel as compared to lower-volatility fuel. The same situation occurred during tests of model year 1957-1971 vehicles in Los Angeles, but the effect on the overall average is less pronounced since a wide variety of vehicles were tested at random times with both types of fuel. EPA[42] has indicated that the test data obtained during the FY 1971 surveillance program will be reanalyzed in the near future to account for the effects of fuel volatility and other procedural factors on the evaporative emissions.

Standard test fuel was employed in both the Denver and Los Angeles evaporative-emission tests for the 1972 vehicles, and the differences in values reported in Table 4.17 have been attributed to the effect of barometric pressure (i.e., 24.5 in. Hg at Denver as compared to 30.2 in. Hg at Los Angeles).

Comparison of the results listed in Tables 4.16 and 4.17 indicates a significant difference in the assessment of the relative importance of evaporative HC emissions on the overall strategy designed to control HC emissions to the atmosphere. The 1975-76 Federal Interim Standards and the 1975-76 California standards for HC exhaust emissions are 1.5 and 0.9 g/mi, respectively. While the SHED-method data are relatively limited, they nonetheless raise a very important issue. These data indicate that vehicles which are supposed to have 95% effective evaporative-emission controls, have evaporative HC emissions that are larger than the 1975-76 exhaust-emission standards when both are compared on a grams-per-mile basis. It has been estimated that refueling losses amount to approximately an additional 0.4 g/mi.[42]

Based on these results, two immediate needs are obvious. First, an accurate test method and procedure for measuring evaporative HC emissions must be developed, which corresponds closely to "real life." It is possible that a careful evaluation of the situation may show that the SHED method is adequate for this purpose. Second, an extensive study should be undertaken to determine the relative importance and cost effectiveness of control strategies designed to control automotive HC emissions based on both exhaust and evaporative HC emission standards.

4.8 Consideration of Nonreactive HC Exhaust-Emission Standards

Presently there is some question about both the absolute magnitude and method of measuring exhaust HC emissions during the federal certification procedure. This concern is based on the fact that national primary and secondary HC air-quality standards are specified in terms of non-methane HC's while the exhaust-emission measurement techniques and standards include methane. Methane has been excluded from the air-quality standards since it is not considered to participate in atmospheric photochemical reactions leading to the formation of photochemical oxidants and since substantial ambient levels of methane are known to originate from uncontrollable sources.

The measurement of total HC exhaust emissions rather than non-methane hydrocarbons was promulgated by the EPA Administrator since: (1) at the time, adequate techniques for the routine measurement of methane in LDMV exhaust were not available; (2) the methane fraction of HC emissions was assumed to be low; and (3) potential emission-control systems were expected to reduce all exhaust HC components equally.[44]

The introduction of oxidation catalysts as an important HC and CO emission-control technology and the development of new instrumentation techniques may invalidate some of the above assumptions.

Ford[45] has recently petitioned EPA to amend the motor-vehicle and motor-vehicle-engine-exhaust-emission test procedures to permit exclusion of methane in determining compliance with federal motor-vehicle-emission standards. The petition includes: (1) information relating to the non-photochemical reactivity of methane; (2) data relating the quantities of methane contained in the exhaust of LDMV equipped with various types of control systems, including oxidation catalysts; and (3) information concerning the availability of instrumentation methods for the measurement of both total and non-methane HC's in automotive exhaust.

Ford's data[45] indicate that methane may represent approximately 10% to 40% of the total HC in the exhaust of catalyst-equipped vehicles. In addition, a good correlation was shown between total HC measured with the standard FID technique and a modified FID technique which has been designed to measure both total HC and methane.

Other laboratries have also reported large concentrations of methane in automotive exhaust from LDMV equipped with oxidizing catalysts. Chrysler[26] has reported data which indicate that mass fractions of unreactive hydrocarbons, including methane and ethane, are increased as the exhaust passes through an oxidation catalyst. In addition, data presented in Table 4.15[33] indicate that the non-methane fraction of total hydrocarbons in automotive exhaust is approximately 94% and 81% for six pre-1974, noncatalyst-equipped vehicles and six catalyst-equipped vehicles, respectively. Data in Table 4.15 also indicate that the fraction of reactive hydrocarbons in the same group of vehicles is approximately 80% and 70% for noncatalyst-equipped and catalyst-equipped vehicles, respectively. In these data, nonreactive HC's were assumed to include methane, ethane, propane, acetylene and benzene. It is important to note that the mass fraction of aldehydes to total hydrocarbons was not significantly different for catalyst-equipped and noncatalyst-equipped vehicles.

It is generally agreed that oxidation catalysts in emission-control systems may preferentially reduce the photochemically reactive portion of the hydrocarbon exhaust. This then leads to the conclusion that the current "total" hydrocarbon standard may unnecessarily penalize vehicles equipped with this type of control system. Thus, the conversion of motor-vehicle exhaust hydrocarbon standards to a nonreactive basis may be a technically desirable goal. However, it is believed that such a change would require significant expenditures of resources by the EPA, motor-vehicle manufacturers, and other motor-testing laboratories for modification of existing equipment and procedures. Furthermore, substantial efforts must also be made to establish revised testing procedures and to determine the magnitudes of nonmethane hydrocarbon emission standards equivalent to present total hydrocarbon standards. In order to obtain information associated with these questions and in response to the petition by Ford,[45] the EPA has recently reported that it is considering changing HC regulations to include only nonmethane hydrocarbons and has requested that all interested parties provide information concerning the following points:

(1) Identification of nonreactive hydrocarbon components of motor-vehicle exhaust which should be excluded in determining compliance with motor-vehicle emission standards. EPA has identified ethane, propane, acetylene, and benzene in addition to methane.

(2) Availability of methods for routine measurement of nonreactive hydrocarbon components in motor vehicle exhaust.

(3) Quantities of reactive and nonreactive hydrocarbon compounds in motor vehicle exhaust.

(4) Impact of total versus reactive hydrocarbon standards.

(5) Lead time required for implementation of nonreactive hydrocarbon testing.

(6) Impact of reactive hydrocarbon standards on other motor vehicle compliance efforts.

A final decision concerning this issue cannot be reached until the additional data requested by EPA[44] have been collected and analyzed from both a technical feasibility and cost-benefits point of view.

4.9 Summary

The CVS-CH exhaust-emission test procedure plays an important role in the federal certification process for 1975 and subsequent model year LDMV, and, hence, it is important to develop an understanding of the statistical variability of exhaust-emission tests that can be expected for vehicles designed to meet these standards. Due to both random and systematic errors, measurements of exhaust emission from a given LDMV have poor repeatability. Various factors including vehicle variability, emission collection and measurement variability and environmental test variables contribute to the poor test reproducibility. In addition to these variations associated with a given vehicle, variations in emissions from a group of similar production vehicles are also encountered.

The results of programs designed to isolate important sources of variability in CVS-CH exhaust-emission tests, other than vehicle variability, have indicated that local ambient test conditions, driver skill, dynamometer design; roll spacing and calibration method, and systematic errors associated with CVS sampling and gas analysis techniques all have an effect on laboratory-to-laboratory exhaust-emission variability. It has been shown that variations in barometric pressure, humidity and test-cell temperature can have a significant effect on HC, CO and NO_x (K_H corrected) exhaust emissions. It has also been shown that vehicle soak temperature, within the allowed range of 60 °F to 86 °F, can influence HC and CO exhaust emissions.

Tests on 1975 type vehicles equipped with oxidation catalysts have shown that the cold transient phase of the CVS-CH test is a major contributor to both the total mass of HC and CO emissions collected during the test and the overall variability of HC and CO exhaust-emission measurements. This is not the case with NO_x where approximately equal masses of NO_x are collected during the three phases of the test.

Variations in exhaust-emission measurements specified in terms of the standard deviation as a percent of the mean for a 1975-76 vehicle in a given cell or from cell to cell at one laboratory can be expected to range between 10% to 25%, 15% to 30% and 5% to 15% for HC, CO and NO_x, respectively. Limited data indicate that the statistical variability of exhaust-emission tests on CVCC stratified-charge type vehicles may be lower than that mentioned above. In addition, systematic errors from laboratory to laboratory of as much as 20% to 30% of mean emission values have also been reported in certain cases. In general, exhaust-emission variability tends to increase as exhaust-emission standards are reduced below 1975-76 levels. Based on these considerations, it is apparent that significant consequences should not be attached to a single CVS-CH exhaust-emission test.

It is concluded that exhaust-emission variability from test to test and laboratory to laboratory can be reduced if the following two programs are developed and implemented:

(1) Establishment of mandatory correlation test programs among governmental, automotive manufacturers' and other test laboratories that are carrying out exhaust-emission measurements on the CVS-CH test. These correlation programs should include CVS-CH tests of relatively stable vehicles and tests of the CVS sampling and gas analysis systems using either exhaust gas generators or premixed gas cylinders as the gas source.

(2) Establishment of close tolerances on ambient test-cell temperature and humidity for the CVS-CH test method and the development of correction factors relating barometric pressure and exhaust emissions.

The mandatory correlation test programs should be designed to determine systematic errors in exhaust emission measurements from cell to cell and between various laboratories. Once systematic measurement errors are isolated at a given facility, they can be corrected or the measurements can be adjusted to take them into account.

It has been shown that one of the important factors contributing to emission-test variability is variation in ambient conditions. Unfortunately, the effect of ambient-condition variations during the CVS-CH test on the exhaust emissions can vary from vehicle to vehicle and, hence, correction factors designed to correct measured exhaust emissions for ambient variations should only be employed when it is impractical to control ambient test conditions. Therefore, it is concluded that the CVS-CH test procedure should be modified to require close control of both ambient temperature and humidity during the course of the test. Presently, no controls are placed on humidity, and ambient temperature is allowed to vary between 68 °F and 86 °F during CVS-CH tests. Good control of ambient temperature and humidity will require the installation of air conditioning systems at most laboratories. Unfortunately, barometic pressure cannot be conveniently controlled during the course of CVS-CH tests. Since barometric pressure has been shown to significantly affect exhaust emissions and both systematic and random variations of barometric pressure occur between test laboratories, it is concluded that a program designed to determine exhaust-emission correction factors for variations in barometric pressure should be developed and incorporated in the CVS-CH test procedure as soon as possible. More stringent control of the temperature range allowed for vehicle soak areas prior to testing would require significant capital expenditures for air conditioning equipment. It is recommended that a program be carried out to determine the cost effectiveness of placing more stringent controls on vehicle soak temperatures.

It has been shown that ambient temperature variations, commonly encountered in large sections of the nation, can significantly increase exhaust emissions of HC and CO for both pre-1975 production vehicles and 1975 prototype models equipped with oxidation catalysts. As an example of this effect, the HC and CO emission from four prototype catalyst-equipped vehicles were shown to increase by 160% and 409%, respectively, over the temperature range 75 °F to 20 °F. The NO_x emissions for these same vehicles increased by approximately 33% over the same temperature interval. Therefore, it can be anticipated that starting a vehicle at temperatures commonly encountered during winter in large sections of the nation, e.g., 0 °F - 32 °F, would cause large increases in exhaust emissions.

Until recently, it had been assumed that evaporative HC emissions had been 95% controlled with respect to uncontrolled evaporative emissions. This conclusion was based on evaporative-emission tests employing the carbon-canister trap method. Evaporative HC emissions measured in two recent surveillance programs, employing the SHED method for both precontrolled and controlled evaporative emissions systems, indicate that this conclusion is not correct.

These data indicate that vehicles which are supposed to have 95%-effective evaporative-emission controls, have evaporative HC emissions that are larger than the 1975-76 exhaust emission standards when both are compared on a grams per mile basis.

In light of these results, an accurate test method and procedure for measuring evaporative HC emissions must be developed, which corresponds closely to "real life." It is possible that a careful evaluation of the situation may show that the SHED method is adequate for this purpose. Also, an extensive study should be undertaken to determine the relative importance and effectiveness of control strategies designed to control automotive HC emissions based on both exhaust and evaporative-emissions standards.

Some concerns have been raised over the methods that are presently employed to determine the deterioration factors of durability-data cars that are subsequently used in the certification procedure. It has been shown that the statistical variability associated with the determination of deterioration factors may reflect the special circumstances of the test rather than the capability of the underlying technology. This idea is particularly relevant when it is realized that deterioration factors are often obtained from emission tests on a single durability data car. An averaging procedure over a larger group of "similar vehicles" might be preferable for deterioration factor calculations. However, if averaging is used too extensively, the averaging will treat all vehicles and systems on equal terms, and attractive technologies may be counterbalanced by less desirable technologies.

Since the deterioration of emission-control systems has been assumed to take place in a linear fashion, it has been suggested that a simple difference technique rather than the ratio technique, which is presently employed for determining deterioration factors, might be more appropriate. Sufficient data were not available to determine which of these two techniques is more appropriate.

Finally, the possibility of modifying the present HC exhaust-emissions standards and measuring techniques to include only reactive HC's has been discussed. This proposal is presently under consideration by EPA and it is suggested that the resolution of this issue should be deferred until the additional data collected by EPA have been analyzed from both a technical feasibility and cost-benefits point of view.

5.0 FUEL ECONOMY TEST METHODS AND PROCEDURES

5.1 Introduction

Due to the present and projected energy shortages, considerable national attention has been focused recently on the fuel economy of LDMV. The development of a rational energy conservation strategy for the transportation sector requires, among other things, a detailed understanding of the factors that influence automotive fuel economy and the development of standardized fuel economy test methods and procedures. The short-term need is to assess, approximately, the validity of present fuel economy tests. The medium-term need is to develop a standardized fuel economy test method and procedure which are representative of average nationwide driving patterns and mileage accumulation. The long-term need is for a more accurate data base which can be employed to make projections of the effects of changes in vehicle technology and use patterns on total U.S. fuel consumption.

Until recently, automotive fuel economy has been primarily the concern of the automotive manufacturers. However, in the past few years, both the public and the government have taken a much more active interest in this area due to the general unavailability and increasing costs of automotive fuel. Unfortunately, at the present time, generally accepted standardized fuel economy test methods and procedures are not available. Due to the significance of this issue, it is important that standardized fuel economy test methods and procedures, based on sound engineering and scientific considerations, be developed as soon as possible.

The present section has been written in an effort to summarize and evaluate information presently available concerning the important factors affecting fuel economy, advantages and disadvantages of alternate fuel economy test methods and procedures, statistical variability of fuel economy measurements and to discuss the effect of cold-start and ambient temperature of LDMV fuel economy.

5.2 Factors Affecting Fuel Economy

The important factors influencing fuel economy of a LDMV include the driving cycle, the vehicle characteristics, the installation of emission-control systems, the driving habits of the consumer and the ambient conditions, including the effect of cold start. The fuel economy of a given vehicle is strongly dependent on the driving cycle employed during the test. The fuel economy tends to be maximized under steady-state cruise conditions. In general, steady-state cruise fuel economies tend to increase as the speed is increased from low values, reach a peak in the range of 30 to 50 mph and then decrease significantly at higher speeds. The effect of steady cruise speeds on the fuel economy of a 2,100 lb subcompact, a 3,500 lb intermediate and a 5,200 lb luxury sedan is shown in Figure 5.1.[46] Figure 5.2 compares the 40 to 70 mph fuel economy of these three vehicles with the fuel economy obtained over an urban driving cycle used by Chrysler.[46] Inspection of these results indicates that the best fuel economy for each vehicle (at 40 mph cruise) is higher by more than a factor of two than its poorest (cold urban cycle) fuel economy. In addition, the fuel economy of a given vehicle is approximately 50% greater for a typical highway cycle than for a typical urban cycle.

The design characteristics of a vehicle strongly influence its fuel economy. In general, the fuel economy of a vehicle on any given driving cycle is affected by: (1) inertia forces that are dependent on the vehicle's mass and acceleration; (2) road load that includes rolling resistance and aerodynamic drag; (3) engine efficiency; (4) drive-train efficiency, including the effects of vehicle transmission and rear axle ratio; (5) accessories, including air conditioning, power steering, etc.; and (6) emission-control devices. Many of the above factors are interrelated, e.g., heavy vehicles tend to have larger frontal areas than lighter vehicles, and, hence, both the inertia forces and aerodynamic drag are often increased on heavy

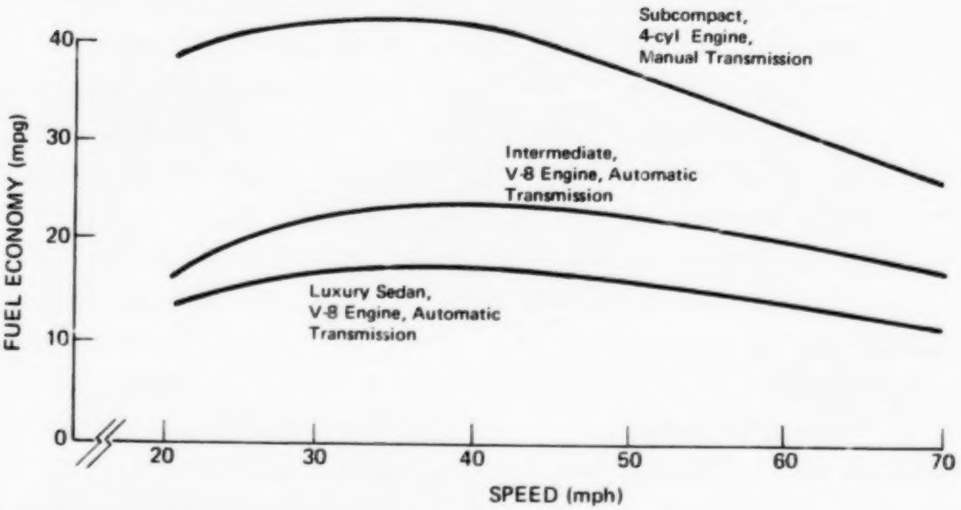

FIGURE 5.1 Cruise Road Load Fuel Economy Versus Speed for Three Vehicles

REF. 46

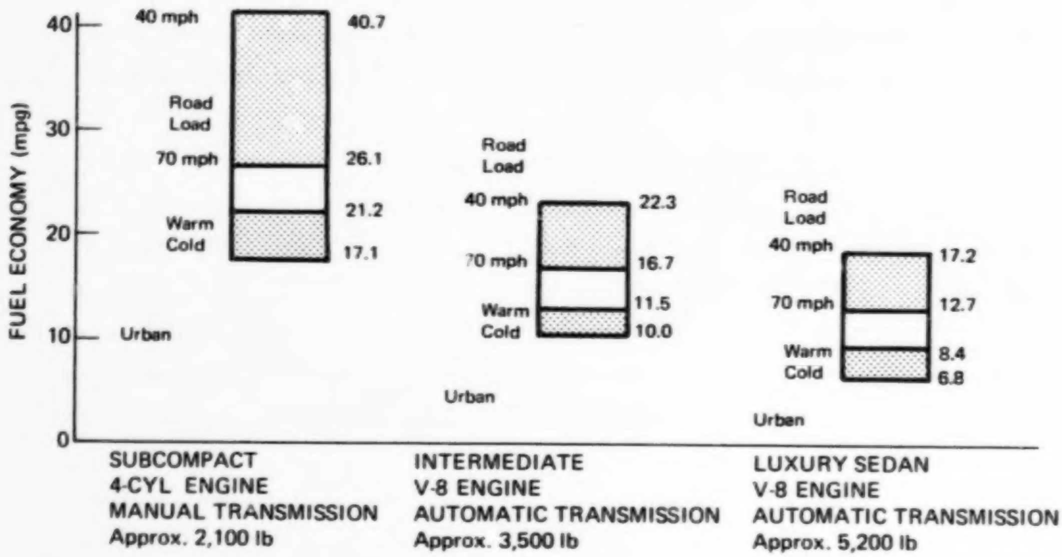

FIGURE 5.2 Fuel Economy Ranges (Urban Cycle to Road Load) for Three Vehicles on Different Driving Cycles

REF. 46

vehicles when compared to light vehicles. Also, in a similar manner, the addition of accessories to a vehicle, such as an air conditioner, not only requires energy for its operation but also increases the inertia forces that the vehicle must overcome. Therefore, it is not a simple matter to optimize simultaneously all of the important parameters influencing fuel economy to achieve the "best" fuel economy. Indeed, it is often even difficult to obtain a base line in fuel economy for comparison purposes since car weights have fluctuated, base engines have changed, some models have been introduced and others dropped etc.

Based on a multiple regression analysis on the measured fuel economies of over 1,400 vehicles as determined for a cold-start urban driving cycle, it has been concluded that vehicle inertia weight is the single most important vehicle parameter affecting fuel economy.[2] These results indicated that a typical vehicle in the 5,000 lb inertia-weight class has approximately a 50% lower fuel economy than a typical vehicle in the 2,500 lb inertia-weight class when the CVS-C driving cycle is used for the comparison.

Since vehicle weight is seen to be an important factor in fuel economy, comments on trends in vehicle weight are relevant. The results of a recent study[47] indicate that the curb weight of passenger cars in all market classes has steadily increased with time in the period between 1956 and 1974. (Note: Inertia weight is generally defined as curb weight plus 300 lb.) The conclusions reached in Reference 47 are summarized below:

1. Passenger cars in all market classes have shown a marked and steady increase in curb weight with time. This curb-weight increase trend is independent of manufacturer. For example, Chevrolet and Ford standard-size cars increased approximately 1,100 lb (33%) and 980 lb (29%), respectively, between 1956 and 1974. In the intermediate class, the Fairlane/Torino series increased curb weight by approximately 1,100 lb (36%) from 1962 to 1974; the Chevelle increased curb weight 900 lb (28%) from 1966 to 1974. In the compact class, from 1962 to 1974, the Chevy II/Nova series increased curb weight by 940 lb (36%), while the Valiant increased by 620 lb (24%).

2. The intermediate-class car of 1974 weighs about the same as the standard size car of 1970 (approximately 4,200 lb curb weight). Similarly, the compact car of 1974 has about the same curb weight as the intermediate car of 1966 to 1970 (approximately 3,300 to 3,600 lb).
3. The overall sales-weighted curb weights of U.S. passenger cars dropped sharply from the 1958 level (approximately 3,700 lb) to approximately 3,450 lb in the 1960 to 1964 period. This was due to the introduction of compacts in 1960 and high sales of both compacts and intermediates in that period. Since 1964, sales-weighted curb weights have risen steadily, reaching approximately 3,650 lb in 1973.
4. The overall U.S. sales-weighted inertia test-weight average (including domestic and foreign cars) has the same general pattern as curb-weight variation with time. It dropped sharply from the 1958 level (3,967 lb) to its lowest value of 3,712 lb in 1961. Since 1961, there has been a steadily rising sales-weighted inertia test-weight trend, reaching a new high value of 3,968 lb in 1973.
5. Curb and inertia test-weight values for domestic passenger cars surpassed their 1958 levels in 1970 and appear to be on a still-rising trend. For example, the sales-weighted inertia test-weight average, for domestic cars only, was 4,223 lb in 1973, compared with 4,096 lb in 1958.

Figure 5.3, which was taken from Reference 47, clearly indicates the general pattern of these weight trends.

The influence of inertia weight on vehicle fuel economy measured on a cold urban driving cycle for 1973 model-year vehicles and an average of pre-emission-controlled (1957-1967) vehicles was also reported in Reference 47. These results are listed in Figure 5.4. Inspection of Figure 5.4 indicates that the fuel economy penalty of a heavy car, from all causes, is very large when compared to light vehicles. It should be noted that although this graph shows a general trend with higher fuel economy at lower inertia weights, the trend is increased by other external factors, such as the consideration that lighter cars tend to have smaller engines, manual transmissions and fewer accessories. These external factors also tend to increase the fuel economy of the lighter cars with respect to heavier cars. Also,

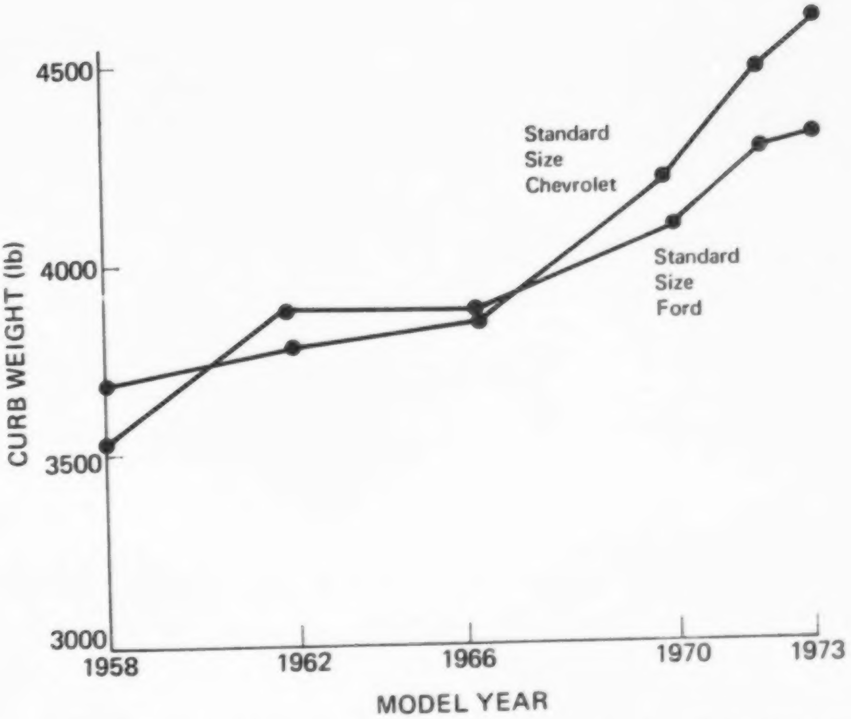

FIGURE 5.3 Vehicle Weight Versus Model Year for Two Standard Size Vehicles

REF. 47

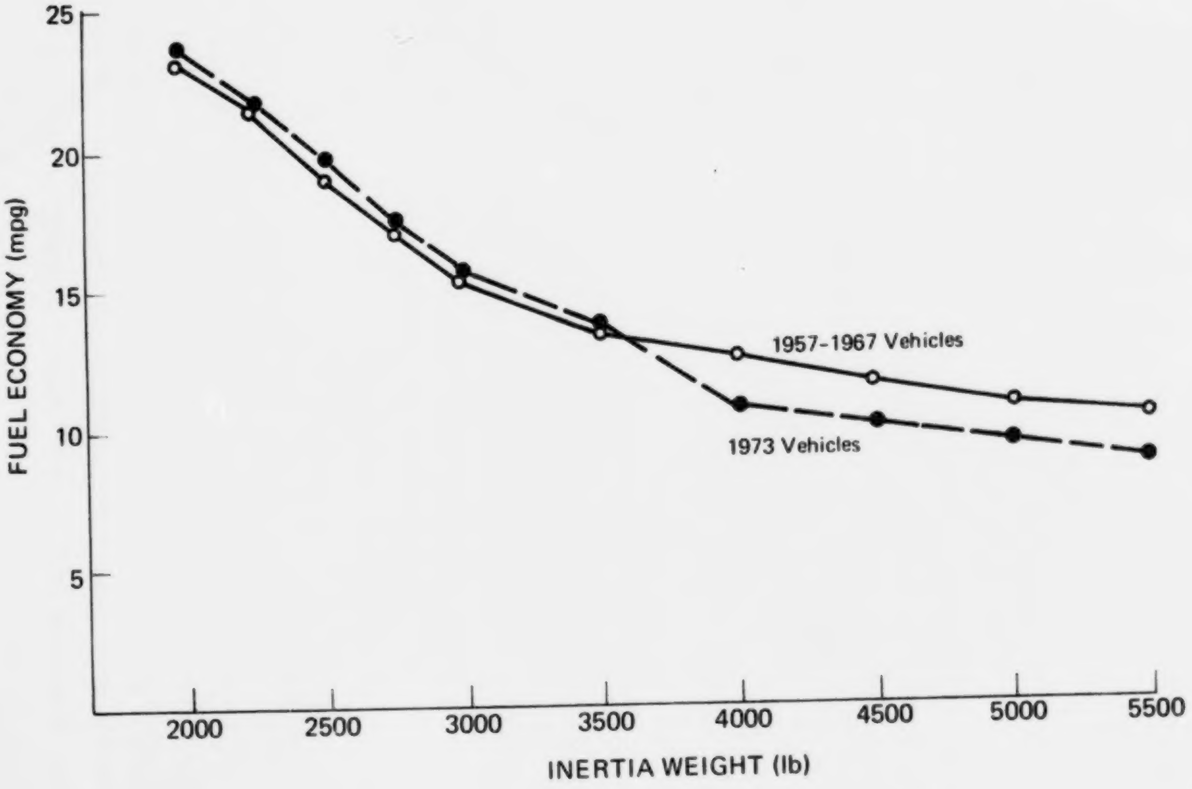

FIGURE 5.4 Fuel Economy of Vehicles on the CVS-C Cycle as a Function of Inertia Weight

REF. 47

Figure 5.4 indicates that a given weight increase has a more significant effect on fuel economy for lighter cars than for heavier cars.

The significance of inertia weight as related to vehicle fuel economy for any given driving cycle on a level road can be readily explained by considering the power that must be supplied to the drive wheels of the vehicle in order to overcome inertia and road load. Power is required to accelerate the vehicle from one speed to another, and once the vehicle is in motion, the drive wheels must provide power to overcome the road load. Road load is usually considered to be due to the sum of vehicle rolling resistance and aerodynamic drag.

The acceleration horsepower is readily computed in terms of the acceleration of the vehicle multiplied by the vehicle speed

$$(HP)_{acc} = m \frac{dv}{dt} v \qquad (1)$$

where

$(HP)_{acc}$ = horsepower required to overcome acceleration load

m = mass of vehicle

v = vehicle speed

$\frac{dv}{dt}$ = vehicle acceleration

Various correlations have been suggested to determine the power required to overcome vehicle rolling resistance. Many organizations have recommended that the power required to overcome rolling resistance, $(HP)_{roll}$, can be accurately represented by the following relationship

$$(HP)_{roll} = mfv \qquad (2)$$

where m and v are as defined above and f is the tire rolling resistance coefficient. The parameter f is difficult to determine accurately and tends to depend on a number of parameters, including tire type, vehicle speed, ambient conditions, tire-inflation pressure, road-surface conditions, etc. There are three common types of tires available--

bias, bias-belted and radial. Typical rolling resistance coefficients for these three types of tires vary as shown in Figure 5.5.[48]

The power to overcome aerodynamic drag, $(HP)_{aero}$, is given by

$$(HP)_{aero} = \frac{1}{2}\rho C_d A v^3 \qquad (3)$$

where

ρ = density of air surrounding the vehicle

C_d = vehicle drag coefficient

A = projected vehicle frontal area

The drag coefficient, C_d, is in the range of 0.4 - 0.6, and the product C_dA ranges from approximately 8 to 15 ft^2 for most LDMV.

The total power required to overcome road load can be computed by adding Equations (2) and (3)

$$(HP)_{\substack{road\\load}} = (HP)_{roll} + (HP)_{aero} = mfv + \frac{1}{2}\rho C_d A v^3 \qquad (4)$$

Inspection of Equations (1) and (4) indicates that the vehicle inertia weight has a direct contribution to two out of the three power terms. The third term, $\frac{1}{2}\rho C_d A v^3$, is also indirectly influenced by the vehicle's weight in that heavier vehicles may have larger frontal surface areas, A, than lighter vehicles.

The relative magnitudes of the horsepower required to overcome rolling resistance, aerodynamic drag and various acceleration rates for a "typical" 4,500 lb inertia-weight vehicle are shown in Figure 5.6. In these computations, the rolling resistance coefficient f, the C_dA term and the air density at standard conditions were taken to be .015, 13 ft^2 and .074 lb/ft^3, respectively. In order to compare $(HP)_{acc}$ with the other power requirements, the acceleration horsepower for two acceleration rates of 4.84 ft/sec^2 (maximum acceleration rate in CVS-CH cycle) and 2.0 ft/sec^2 is also plotted in Figure 5.6.

In general, due to the magnitude of the coefficients and the cubic dependence on velocity, the aerodynamic horsepower, $(HP)_{aero}$, is insignificant in urban low-speed driving when compared to the

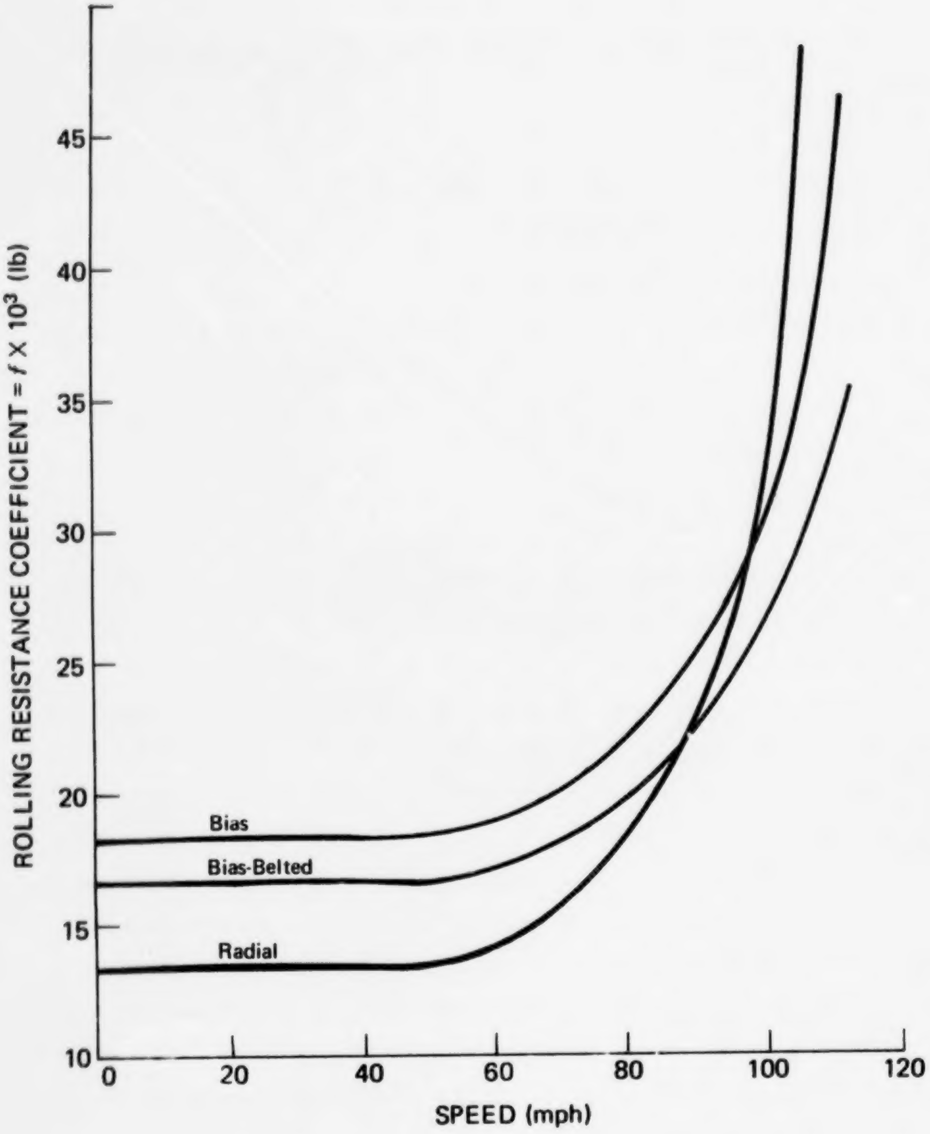

FIGURE 5.5 Tire Rolling Resistance as a Function of Speed

REF. 48

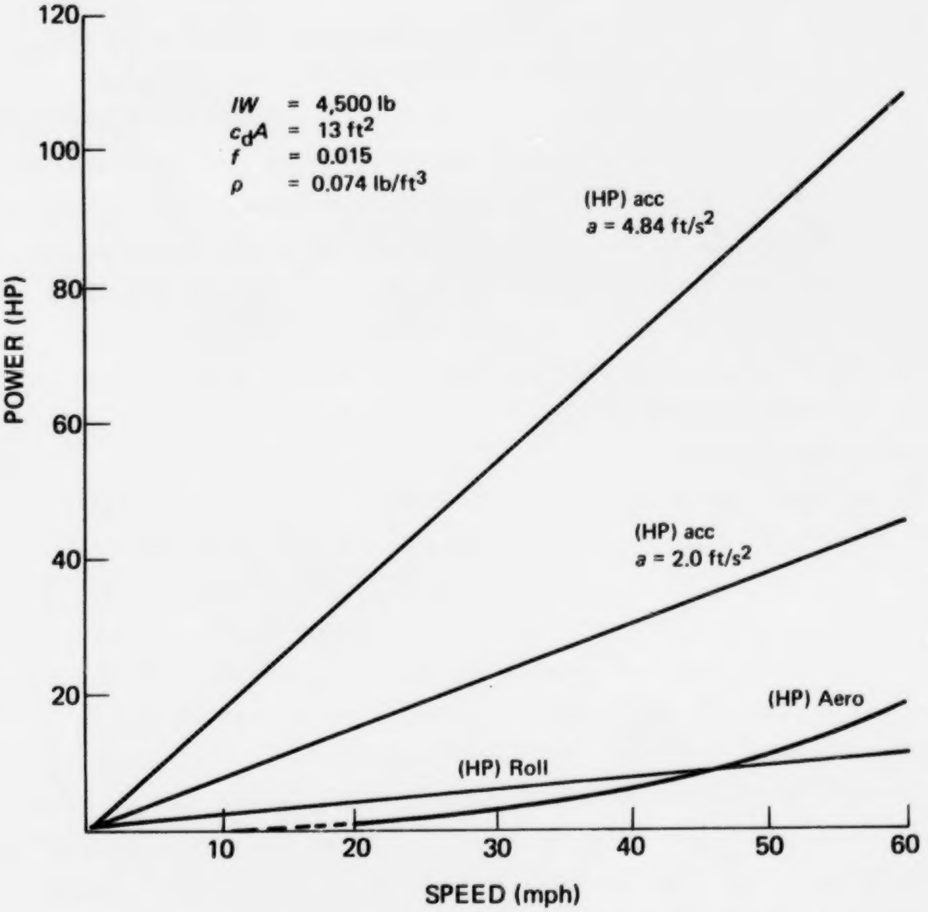

FIGURE 5.6 Horsepower Required to Overcome Inertia, Aerodynamic and Rolling Loads as a Function of Speed for a Specific Vehicle

rolling resistance horsepower, $(HP)_{roll}$. However, the importance of aerodynamic drag on total road-load horsepower becomes very significant at high speeds. Thus, at high speeds the aerodynamic styling of the vehicle will have a significant effect on both the vehicle's fuel economy and its maximum speed.

Obviously, the aerodynamic drag must also be a function of the surrounding air velocity in the form of head winds and crosswinds which can significantly affect fuel economy. Inspection of Figure 5.6 also indicates that the instantaneous power required to accelerate the vehicle at 4.84 ft/sec^2 is very significant when compared to the road-load power at the same speed. Even relatively moderate accelerations, 2 ft/sec^2, require significant instantaneous power outputs when compared to road load in order to overcome the inertia effects. Since the product C_dA is not a linear function of a vehicle's mass, the relative importance of aerodynamic drag tends to increase for lower inertia-weight vehicles.

The spark-ignition, internal-combustion engine does not efficiently convert the energy released from the combustion process to mechanical work available at the drive shaft. In the theoretical limit, an ideal spark-ignition engine with a compression ratio of approximately 8.2 could attain a maximum thermal efficiency in the range of 57%. However, this ideal efficiency represents an engine operating without heat losses to the cooling water or lubricating oil, without energy losses due to friction drive train or pumping losses and without combustion inefficiencies etc. Due to these and other factors, actual spark-ignition engines only have thermal efficiencies in the range of 20%. An estimate of the percent of energy liberated by the combustion process available to propel the vehicle and drive the vehicles accessories along with an estimate of the relative magnitude of the losses as a function of vehicle cruise speed are shown in Figure 5.7.[49] In general, increasing engine compression ratio within operational limits results in both fuel economy and acceleration

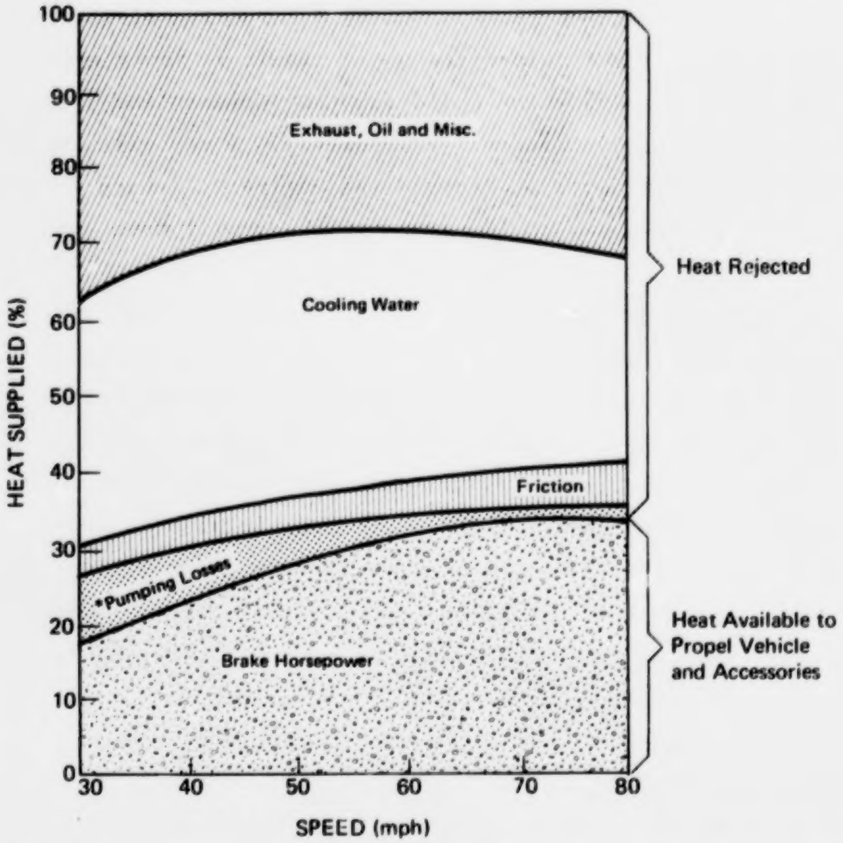

FIGURE 5.7 Energy Balance for a Typical Spark-Ignition Engine as a Function of Cruise Speed *(Pumping losses occur during the intake stroke and partial throttle setting and result from the piston pushing against the atmospheric pressure in the crankcase offset by partial vacuum in the combustion chamber.)

REF. 49

gains, whereas, an increase in engine displacement tends to result in fuel economy losses and acceleration gains. An increase in engine displacement does not necessarily result in fuel economy losses since an increase in displacement could be accompanied by a reduction of the axle ratio. A reduction of the axle ratio would result in lower engine speed at the same vehicle speed which could tend to increase the fuel economy of a given vehicle. In general, a numerically lower axle ratio will allow for a better fuel economy because the engine will turn slower for a given vehicle speed at the same power and will have less internal friction.

The axle is only one of the driveline characteristics that can affect fuel economy. Another source of fuel economy loss is within the automatic transmission with its associated torque converter slippage. A change from a high-slip loose to a low-slip, tight-torque converter can increase fuel economy. The basic fuel economy difference between a manual and automatic transmission should also be considered. In general, a manual-transmission-equipped vehicle will obtain better fuel economy than the equivalent automatic-transmission-equipped vehicle. However, depending on the test cycle, the vehicle speed, and the rear-axle ratio, it is possible for an automatic-transmission-equipped vehicle to obtain better fuel economy than a manual-transmission vehicle.

The state of a vehicle's maintenance can also affect its fuel economy. Proper tire inflation and wheel alignment can reduce rolling resistance and improve fuel economy. In addition, the state of a vehicle's tune and other calibration factors can significantly affect fuel economy.

The addition of convenience accessories such as air conditioning, power steering, power brakes, heater and defroster blowers, power windows, power seat adjusters, lighting systems, etc. can also significantly lower a given vehicle's fuel economy. For example, the estimated penalty in fuel economy over an unequipped car for air conditioning is 9% to 20%. In general, all power-assist devices decrease the vehicle's fuel economy because they require additional power to operate and add weight to the vehicle.

It is generally acknowledged that the fuel economy of many vehicles has decreased due to the introduction of emission controls. However, the magnitude of this decrease is a relatively controversial subject. EPA[2] has compared the fuel economies, measured on the CVS-C test cycle, of pre-controlled vehicles (1957-1967 average) to the fuel economy of 1973 vehicles as a function of inertia-weight class. Their results indicated the fuel economy of vehicles in all inertia-weight classes up to 3,500 lb obtained slightly improved fuel economy even in spite of the installation of emission controls while vehicles in the inertia-weight class 4,000 lb and above have poorer fuel economy (ranging from approximately 14% to 18%) than comparable uncontrolled vehicles. Other authors have contributed a greater fuel economy penalty to emission controls.

Since vehicles are not generally driven by the consumer in the steady-state cruise mode and an individual driver strongly influences the rate of accelerations and decelerations, the fuel economy obtained by different drivers over the same route under identical traffic conditions will vary significantly.

Significant differences have been reported for fuel economy of vehicles for a trip started from a "cold-start condition" as compared to the fuel economy for the same trip and vehicle when it is started from a "hot-start condition." Data, which will be discussed in more detail in Section 5.6, have indicated that short trips in the range of 3 to 5 mi initiated from a cold-start condition can result in fuel economy penalties of as much as 20% to 35% when compared to fuel economy of a fully warmed-up vehicle. In addition, variations in ambient conditions affect vehicle fuel economy.

The preceding discussion has been designed to provide an overview rather than a dissertation on large numbers of important factors that influence the fuel economy of a LDMV. Based on these discussions, it can be concluded that the relative fuel economy of various vehicles can only be reported with any degree of certainty if standardized fuel economy test methods and procedures are developed.

5.3 Test Methods and Procedures

The critical elements in any standardized fuel economy test method and procedure must include: a representative standard driving cycle or cycles; a method to determine the mass or volume of fuel consumed and the distance traveled during the test; and a procedure for simulating vehicular loads encountered during the course of the driving cycle.

Questions concerning the development and choice of appropriate fuel economy driving cycles have been discussed in Section 3.4. These considerations led to the conclusion that since driving patterns change with time and two drivers would tend to drive the same route in a different manner, it is impossible to develop an absolutely typical fuel economy driving cycle. However, it was recommended that two standardized fuel economy driving cycles, one designed to represent urban fuel economy and one designed to represent highway driving, be adopted to evaluate the relative fuel economies of various automotive designs and to compare the relative fuel economies of one vehicle versus another in order to allow rational consumer choice.

Two techniques have been commonly applied to measure fuel economy. In the first technique, a direct measurement of the mass or volume of fuel used during the course of the test is obtained from appropriate instrumentation and this data is used in conjunction with the distance traveled and conversion factors to compute the vehicle fuel economy in miles per gallon (mpg). The second technique may be termed the Carbon Mass Balance Method. When employing this technique, the HC, CO and CO_2 emissions are collected and measured during the course of the driving cycle as in the CVS-CH test procedure. Since the mass of carbon per gallon of gasoline is known, the measurement of the vehicle emissions during the course of the test can be employed in conjunction with the distance traveled to compute a fuel economy based on the concept that carbon mass is conserved. The major assumptions required when using this technique include:

1. The carbon contained in the HC, CO and CO_2 in the exhaust is the only carbon in the exhaust. This means that other carbon-containing compounds, such as oxygenated hydrocarbons that are not detected by a Flame Ionization Detector (FID) and carbonaceous particulates, are ignored.

2. All of the carbon that is measured in the exhaust in the form of HC, CO and CO_2 came from the fuel; there are no other sources of carbon.

3. All the fuel consumed during the test can be accounted for by the carbon in the exhaust. This means that all of the fuel that leaves the tank during the test is assumed to pass through the engine and that no carbon leaks out of the exhaust system before being analyzed or evaporates from the vehicle.

Both of these test methods for fuel economy measurements have advantages and disadvantages and are subject to significant errors if careful experimental techniques and procedures are not followed. However, under conditions where both techniques can be simultaneously employed, either method can be used to obtain accurate measurements of fuel economy. An early study designed to examine the correlation between measured fuel economies based on the Carbon Mass Balance and weighing techniques was reported in Reference 2. In this study, eight CVS-C tests were conducted at the EPA Motor Vehicle Emission Laboratory in Ann Arbor, Michigan, on three different vehicles. The average difference in fuel economy (calculated fuel economy minus weighted fuel economy, divided by weighted fuel economy) was found to be 4.5% with the calculated fuel economy being higher than the weighed fuel economy. The individual differences ranged from 2.6% to 8.1%. Another investigation was performed using data from the work reported in Reference 2. The same calculation was performed on 245 sets of data for which there were both a fuel weight and HC, CO and CO_2 data. The same type of calculation yielded a 3.3% difference with the standard deviation of the difference being 8.1%. Conversations with a number of individuals from various laboratories during the course of the present study suggested that excellent correlation can presently be obtained between the two fuel economy test methods discussed above.

Recent data obtained from an automotive company[50] in which three vehicles were tested nine times each on both the CVS-CH cycle and the EPA highway cycle have indicated that the standard deviation as a percent of mean for fuel economy measurement based on fuel-metering techniques and the Carbon Mass Balance method are approximately equal. These results are given by:

Cycle	$\frac{s}{\bar{x}}$ Carbon Balance Method	$\frac{s}{\bar{x}}$ Fuel Meter Method
CVS-CH	2.7%	1.9%
EPA's Highway	1.6%	1.9%

All of these results indicate that either the fuel meter method or the Carbon Mass Balance Method can be successfully employed to accurately determine fuel consumption if careful experimental techniques and procedures are developed and followed during testing. Alternate satisfactory techniques are readily available to determine distance traveled during the test.

Once the fuel economy driving cycles and procedures for determining fuel consumption and distance traveled have been defined, one must specify how the appropriate inertial and road loads are to be applied to the vehicle as it traverses the specified driving cycle. Basically, two alternate procedures have been suggested. First, there is the obvious dynamic technique of simply driving the vehicle on the road or on a test track with appropriate instrumentation to allow the driver to follow the given velocity versus time cycle. The second technique that has been proposed is to simulate the actual loading of the vehicle during the course of the driving cycle with the aid of a chassis dynamometer. It should be noted that there is no inherent technical reason for eliminating the use of chassis dynamometers from fuel economy testing if it can be shown that they accurately represent the actual inertial, aerodynamic rolling resistance and accessory loads experienced by the vehicle as it traverses the driving cycle. Both the road or track and dynamometer procedures have inherent advantages and disadvantages as outlined below.

The advantages of a road or track test procedure include:

1. The total load, including inertia loads, road loads and the effects of accessory loading are accurately simulated.
2. Fuel economy tests may be carried out anywhere a suitable level stretch of pavement can be found.
3. Assuming that an appropriate road or track is available, relatively low expenditure for capital is required.

Disadvantages of road and track testing include:

1. Testing cannot be carried out under adverse weather conditions.
2. Correlation parameters, designed to take into account the effects of ambient variables on fuel economy measurements, must be developed and applied to the base data in order to obtain fuel economy measurements at standard conditions.
3. Some difficulties are encountered with reproducibility of vehicle speed versus time especially when complex cycles, such as the UDDS or proposed EPA highway cycle, are employed.
4. There is a lack of a satisfactory evaluation of the effect of cold start on fuel economy.
5. Fuel economy and exhaust emissions cannot be simultaneously measured.

The advantages of test methods based on the use of a chassis dynamometer include:

1. The test can be conducted independent of local weather conditions.
2. Since test cell conditions can be controlled, correction factors for the effect of ambient conditions on experimental results are minimized.
3. The same driving cycle (speed versus time trace) can be followed within specified close tolerances.
4. Fuel economy and exhaust emissions can be simultaneously measured.

There are also a number of disadvantages to employing a chassis dynamometer test procedure. These include:

1. Total load simulated on the chassis dynamometer may not accurately duplicate the rolling resistance and aerodynamic drag experienced by the vehicle on the road.
2. In general, the cooling fan airflow characteristics in a dynamometer facility do not exactly reproduce the airflow characteristics of a moving vehicle. Therefore, the effect of vehicle warm-up may be slightly different than that encountered on the road.
3. The present method of accounting for the existence of air conditioning, by setting in the dynamometer a 10% increase in road load horsepower at 50 mph, may not exactly duplicate the overall effects of air conditioning on fuel economy.
4. The large discrete inertia-weight differences, 250 lb and 500 lb on the chassis dynamometer presently employed for fuel economy testing that are used to simulate load may bias the simulated load too high or too low for a given vehicle due to the vehicle's true inertia weight being too close to the cutoff point between inertia-weight classes. Due to the manner in which inertia-weight loads are presently set in the CVS-CH test method, a vehicle at the upper limit of a given weight class receives a fuel economy advantage over its expected road fuel economy in the range 5% to 8%. Conversely, a vehicle at the low end of the inertia-weight class receives a penalty in the range 5% to 8%. These computations were obtained using EPA's[2] simple correlation of fuel economy versus inertia weight.

EPA has simultaneously measured the fuel economy and emissions of LDMV operating on both the CVS-C and CVS-CH test cycles. The test cycles have been driven on a chassis dynamometer and the test methods and procedures have been similar to the one utilized during the course of emission testing. The fuel consumed during the test has been generally measured by the Carbon Mass Balance Method, and the fuel economy has been computed by dividing the cycle distance by the volume of fuel consumed during the course of the test. Data obtained in this manner have taken into account effects due to both cold-start and hot-start conditions, and the results have been reported as representative of urban fuel economy.

In addition to measuring and reporting urban fuel economy as determined during the CVS-CH test, EPA plans to measure and report highway fuel economies for 1975 model-year vehicles. The EPA highway cycle (see Section 3.4) will be employed for these tests. As in the case of the urban fuel economy data, the cycle will be driven on a chassis dynamometer, the fuel consumed will be measured by the Carbon Mass Balance Method, and the vehicle's highway fuel economy will be computed by dividing the length of the highway cycle by the fuel consumed. These results will correspond to a hot-start highway driving cycle since the highway cycle will be driven after the CVS-CH cycle is completed.

The SAE[18] has recently adopted a set of recommended practices for fuel economy measurements based on a road and track test procedure. Reference 18 recommends four driving cycles (see Section 3.4), all of which are to be driven on a road or track. Complete specifications of the recommended practice may be found in Reference 18. All tests are to be carried out on a fully warmed-up vehicle. Fuel economy will be based on the average fuel consumed and distance traveled on two successive runs over the course. The test is to be repeated until two successive tests repeat within 2% for fuel consumption and 1% for elapsed time. The measured fuel economy is subsequently corrected to standard conditions by multiplying the measured value by empirical correction factors designed to account for fuel properties and ambient variations.

5.4 Statistical Variation of Fuel Economy Measurements

As in the case of exhaust emissions, information concerning the statistical variability of fuel economy measurements is of importance. Information concerning the variability of measured fuel economy in a given test cell or test track, the variability of measurements from cell to cell at a given laboratory and the variability of measurements from laboratory to laboratory for a given vehicle are of interest. Another major concern in fuel economy measurements is the problem associated with the estimation of the fuel economy of an entire class of vehicles based on tests carried out with a single or small number of vehicles from that class. This type of error in reported fuel economy is due mainly to the vehicle-to-vehicle variability. Data obtained during this study concerning statistical variations in fuel economy measurements are summarized below.

Due to the recently developed concern with fuel economy, only a small amount of the data required to examine the variabilities mentioned above is readily available. However, since a large amount of the exhaust emission data has included CO_2 and since CO_2 is by far the predominate factor in determining fuel economy based on the Carbon Mass Balance Method, the statistical variability of CO_2 emission data may be readily used to estimate the statistical variability of fuel economy. Whenever possible, actual reported fuel economy data will be quoted.

As previously noted in Section 4.3, EPA[22] has reported the results of 30 CVS-CH tests designed to determine the reproducibility of both emissions and fuel economy. The Carbon Mass Balance Method was used to determine fuel economy. The results of these tests give an average fuel economy and standard deviation as percent of the mean of 10.31 mpg and 2.6%, respectively. Since the CVS-CH procedure has a cold start and a hot start, the emission data for this vehicle in a given cell can be used to calculate both hot-start and cold-start fuel economy. Emissions from bag 1 were used to calculate a cold-start fuel economy while emissions from bag 3 were used to compute the hot-start fuel economy. The hot-start fuel economy and standard deviation as percent of the mean were computed to be 11.85 mpg and 2.5%, respectively, as compared to the cold-start values of 10.03 mpg and 2.6%.

Another study, previously discussed in Section 4.3, reported CO_2 emissions for 16 CVS-CH tests of a Chevrolet Impala equipped with an oxidizing catalyst in a single test cell.[23] As shown in Table 4.3, the CO_2 standard deviation as percent of the mean was reported to be 1.2%. As previously stated, this indicates that the fuel economy variation as percent of the mean was also approximately 1.2%.

The fuel economy variation of a 1973 model-year production vehicle has been reported for a number of different cells at the same laboratory.[26] A CVS-H test procedure was followed and the fuel economy was computed based on the Carbon Mass Balance Method. The range of data obtained in five different test cells is given by

Number of Tests at Each Cell	Mean Fuel Economy For Each Cell $\bar{x}$, mpg	$\frac{s}{\bar{x}}$
13-18	10.83-11.51	2.8%-5.5%

A vehicle equipped with an oxidizing catalyst has been tested several times over the CVS-CH cycle in various cells at Chrysler Corporation and three times in one test cell at EPA in Ann Arbor.[26] Fuel economy was not reported, but the CO_2 standard deviation as percent of mean (see Table 4.6) was 10.6% and 2.1% at Chrysler and EPA, respectively.

An automobile manufacturer[50] has reported that the test-to-test fuel economy standard deviation of a single vehicle tested on a track procedure as 1.1% of the mean. This variability may be due to the fact that road fuel economy data are often rejected as part of the standardized test procedures if the average fuel economy for two runs up and down the track is not within specified close tolerances.

Once the cell variation has been established, the cell-to-cell variation in a given laboratory may be examined. Some REPCA I data for cell-to-cell variability of fuel economy as measured on the CVS-H cycle have been obtained.[26] In addition, similar data from another laboratory have been obtained for a 1973 model production vehicle on a CVS-H cycle.[26] These data are summarized below:

Laboratory	Total Number of Tests	Total Number of Cells	Total Mean Fuel Economy $\bar{x}$, mpg	$\frac{s}{\bar{x}}$
General Motors	70	4	13.61	1.8%
Chrysler	90	6	11.08	4.4%

The next level of complication is to determine a representative laboratory-to-laboratory variability of fuel economy measurements. The SAE Fuel Economy Task Force has carried out a round robin fuel economy program for three vehicles at various laboratories. The tests were carried out using the CVS-C test procedure and fuel economy was determined by the Carbon Mass Balance Method.[26] The results of this study are summarized in Table 5.1.

The results of another correlation study[50] are listed in Table 5.2. The tests were carried out on three vehicles operating on the CVS-H test. The overall results listed in Table 5.2 are based on a simple pooling of all data.

Reference 50 has reported data relating to the vehicle-to-vehicle variation in fuel economy among samples of identical vehicles. A test-track procedure was used to determine the desired fuel economy and the

Table 5.1 Summary of Round Robin Fuel Economy Test Program

	Compact 6 Cyl.	Compact V-8	Full Size V-8
No. of Laboratories	5	5	6
No. of Tests	8	7	8
Mean CVS Fuel Economy	15.6 MPG	11.8 MPG	11.0 MPG
Standard Deviation of Tests	.95 MPG	.45 MPG	.97 MPG
Percent Std. Dev. of Tests	6.1%	3.8%	8.8%
Range of Fuel Economy	14.3-16.7	11.3-12.4	9.6-11.0

Dynamometer Horsepowers Set Per Federal Register

REF. 26

Table 5.2 Summary of CVS-H Fuel Economy within, between and over Various Laboratories[1]

	Vehicles								
	1973 2.6L Capri			1974 351W Montego			1974 460 T'Bird		
Facilities	$\bar{x}$	s	s/$\bar{x}$	$\bar{x}$	s	s/$\bar{x}$	$\bar{x}$	s	s/$\bar{x}$
1. Environmental Protection Agency	20.0	.54	.027	12.6	.24	.019	10.5	.61	.058
2. Ford Emission Test Laboratory (ETL-75)	19.7	.56	.028	12.5	.12	.010	10.5	.16	.015
3. Ford Emission Test Laboratory (ETL-74)	19.7	.59	.030	12.4	.15	.012	10.6	.23	.022
4. Ford Allen Park Testing Laboratory	19.6	.30	.015	12.6	.19	.015	10.7	.10	.009
5. Ford Los Angeles Laboratory	18.7	.21	.011	-	-	-	9.7	.15	.016
6. California Air Resources Board	18.9	.22	.012	-	-	-	10.5	.17	.016
Overall	19.5	.64	.033	12.5	.20	.016	10.4	.51	.049

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[1] Tests at EPA and ETL-75 were conducted with 1975 CO instrumentation. Testing at ETL-74 and remainder of facilities were with 1974 CO instrumentation.

$\bar{x}$ - fuel economy in mpg

s - standard deviation in mpg

$\frac{s}{\bar{x}}$ - standard deviation as percent of mean

REF. 50

data for a large number of measurements indicated that the vehicle-to-vehicle variation in fuel economy, $\frac{s}{\bar{x}}$, is 3.5%. Reference 50 also reported the results of a study conducted to determine the variability of results from both test-track and laboratory fuel economy tests. The study concluded that with a single vehicle the true population mean can be established within ± 6.5% for the Ford City-Suburban cycle (test track) and ± 11.02% for the CVS-C cycle (dynamometer) with 90% confidence. The sample sizes required to predict mean fuel economy for a given car line within ± 3% of the true population mean at 90% confidence was estimated to require testing of five vehicles for the test-track cycle compared to 14 vehicles for the laboratory dynamometer cycle. Another source[25] has reported that the fuel economy and standard deviation as percent of mean for CVS-CH tests on 38 different 1.5-liter, stratified-charge CVCC production vehicles was 25.2 mpg and 3.6%, respectively.

5.5 Reliability of Fuel Economy Measurements Based on Chassis Dynamometer Tests

The ability of any fuel economy test procedure, incorporating a chassis dynamometer as one of its elements, to accurately determine the fuel economy of a vehicle over a specified driving cycle has been questioned. It has been previously stated in Section 5.3 that there is no inherent technical reason for eliminating the use of chassis dynamometers from fuel economy testing if it can be shown that they adequately simulate the actual inertial, aerodynamic, rolling resistance and accessory loads experienced by a vehicle as it traverses the driving cycle. Unfortunately, the results of definitive studies designed to address this question are not presently available. However, due to the importance of this issue, the limited data which are presently available concerning the repeatability and accuracy of fuel economy test procedures incorporating a chassis dynamometer as the elements for both urban and highway driving cycles are discussed below.

The test results presented in Section 5.4 indicate that fuel economy measurements employing chassis dynamometers for an urban driving cycle (e.g., CVS-H, CVS-C and CVS-CH tests) are reasonably repeatable. In fact, the data indicate that the variability of measured fuel economy in terms of the standard deviation as a percent of the mean in a given cell, from cell to cell at a given laboratory and from laboratory to laboratory is in the range of 2% to 8%. The limited data obtained for reproducibility studies on the EPA highway cycle have indicated a similar variability.

Questions relating to the ability of a chassis dynamometer to adequately represent the inertia and road loads as a function of speed for a given vehicle are also of importance. In addition, it would be desirable to have data relating to the importance of variations in loading on fuel economy measurements. It is generally agreed that dynamometers with twin small-diameter rolls, such as the Clayton-type units presently utilized by EPA, do not provide the same tire-roll loading effects as those found on the road. It is possible to minimize inaccuracies in dynamometer loading if the load on the dynamometer is set so that vehicle coast-down time on the rolls matches vehicle coast-down times obtained on the road. In addition, the Clayton-type units are generally limited in load adjustment and inertia-weight increments. The Federal Register presently specifies 250 lb inertia-weight increments for low inertia-weight vehicles in the range 1,500 to 2,750 lb and 500 lb inertia-weight increments in the range 3,000 to 5,000 lb. The effect that this test procedure has on dyno versus expected road fuel economy has been discussed in Section 5.3.

Large-roll electric dynamometers provide independent adjustment of simulation for aerodynamic drag and rolling resistance plus excellent vehicle mass simulation. However, these dynamometers are significantly more expensive than small-roll units.

Data reported in Reference 29 have indicated that the dynamometer load applied by a Clayton-type dyno while driving the CVS-H cycle with three different inertia-weight vehicles was a function of both dyno-roll spacing and dyno-calibration method. The total work (measured by drive shaft torque) during the CVS-H test using 20 in. roll spacing versus 17¼ in. roll spacing on all inertia-weight vehicles was higher by an average of 1.3%. However, analysis of the data indicated that roll spacing had no significant effect on CO_2 emissions and, hence, it can be concluded that roll spacing did not have a significant effect on fuel economy.

The dynamometer calibration technique for setting road load at 50 mph was also shown to affect total work required to drive the CVS-H cycle. Differences in work ranging from 1.2% less total work for the 3,000 lb inertia-weight vehicle to 2.4% more work for the 5,500 lb vehicle were reported as a function of dynamometer-calibration method.

Another manufacturer[51] has reported that the calibration of the indicated load on a given Clayton-type dynamometer is not as reproducible as might be desired and that this factor may cause variations of as much as 10% in fuel economy measured for low inertia-weight vehicles on the CVS-CH test.

The SAE-recommended urban, suburban and 70-mph interstate driving cycles fuel economies were determined at three different test tracks, one road site and on a large roll chassis dynamometer. The results of these tests are summarized in Table 5.3.[52] The road loads on the large-roll, mechanical-chassis dynamometer were set by matching as closely as possible the coast-down times of the vehicles on the River Road Highway to the dyno coast-down times. Coast-down times could be accurately matched for the two heavy vehicles, but due to internal friction in the dynamometer, the road coast-down times for the light vehicle could not be simulated. Therefore, numerous tests at different dyno loads were carried out for the low inertia-weight vehicle. Due to this problem,

Table 5.3 Fuel Economy Measurements as Measured on Both Road Track Tests and Dynamometer Tests

Vehicle	Company	Load Facility	Corrected Fuel Economy		
			SAE Urban Cycle (mpg)	SAE Suburban Cycle (mpg)	SAE 70 mph Interstate Cycle (mpg)
1973 Dodge Charger IW = 4,400 CID = 318-2V	Chrysler	Track	10.2	17.3	15.8
	GM	Track	10.3	17.4	16.1
	Ford	Track	10.2	16.7	15.4
	Chrysler	Track	10.0	17.2	15.8
	Shell	River-Road Highway	10.1	16.5	15.1
	Shell	Dyno	9.9	16.3	15.0
1973 Buick Century IW = 4,620 CID = 350-4V	Chrysler	Track	9.9	15.5	14.0
	GM	Track	10.1	15.6	13.8
	Ford	Track	9.7	15.2	13.7
	Chrysler	Track	9.9	15.5	14.0
	Shell	River Road	10.3	15.9	14.0
	Shell	Dyno-normal load	10.0	15.6	14.3
	Shell	Dyno-light	9.8	15.6	14.6
1973 Ford Pinto IW = 2,740 CID = 122-2V	Chrysler	Track	15.4	22.4	18.3
	GM	Track	15.8	22.5	18.8
	Ford	Track	15.5	22.4	18.5
	Chrysler	Track	15.6	22.8	18.9
	Shell	River Road	16.2	22.7	18.7
	Shell	Dyno-Load$_1$ *	14.3	20.0	16.1
	Shell	Dyno-Load$_2$ *	14.9	20.8	18.3
	Shell	Dyno-Load$_3$ *	14.7	22.6	19.2
	Shell	Dyno-Load$_4$ *	15.2	25.4	23.0

*Dyno-Load$_1$ to Dyno-Load$_4$ represent decreasing dynamometer loading.

REF. 52

one should not expect to obtain good agreement between the fuel economies measured on the track and the dynamometer for the low-weight vehicle. It should be noted that the dyno was designed and constructed for testing of vehicles near 4,000 to 5,000 lb and that the dyno could have been designed to minimize internal friction which would allow coast-down times for low inertia-weight vehicles to be accurately reproduced.

Inspection of the data, reported on all three driving cycles for the two heavy vehicles, indicates that excellent agreement within 1% to 4% of the test-track mean can be obtained on a large-roll chassis dynomometer if care is taken to set the dyno load to reproduce actual road coast-down times. The results for the low inertia-weight vehicle indicate that significant errors in fuel economy can occur for dynamometer tests if road load is not adequately simulated by the dynamometer.

Another laboratory has reported fuel economies of eight vehicles for the EPA highway cycle as measured on both a dynamometer and a test track.[26] The fuel economy of the vehicles driven on the SAE 55-mph interstate cycle was also measured on the test track. These data are presented in Table 5.4, and the measured dyno versus track results for the EPA highway cycle are graphically represented in Figure 5.8. The dynamometer data were obtained on a Clayton-type dyno, and the road load at 50 mph was set according to the "cook book" method established in the Federal Register.

Inspection of these data indicates that, in all cases, the fuel economy measured on the dynamometer is larger than the value obtained on the track. Percentage differences in the values (fuel economy dyno minus fuel economy track divided by fuel economy dyno) range from approximately 4% to 16%. It is also important to note that fuel economies measured on the track for these eight vehicles as measured on the SAE 55-mph interstate cycle are in good agreement with values obtained on the EPA highway cycle.

Various sources have analyzed the energy required to drive a vehicle over the CVS-CH cycle, and it has been shown that inertia forces and

Table 5.4 Comparison of Fuel Economies for Highway Cycles Measured on a Track and on a Dynamometer[1]

			Fuel Economy (mpg)		
			Dyno Test	Track Tests	
Body	Engine Displ. (CID)	Inertia Weight	EPA Highway Cycle	EPA Highway Cycle	SAE Interstate 55 Cycle
'A' Body	225	3,500	25.7	22.6	21.5
'B' Body	318	4,000	20.9	17.5	17.4
'B' Body	360	5,000	18.1	16.6	16.5
'B' Body	360	5,000	18.6	15.9	16.1
'C' Body	400	5,000	17.4	16.2	16.2
'C' Body	400	5,000	14.6	14.0	14.4
'C' Body	440	5,000	16.7	-	15.8
'C' Body	440	5,000	17.6	16.4	16.4

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[1] Dyno-load set as per Federal Register.

REF. 26

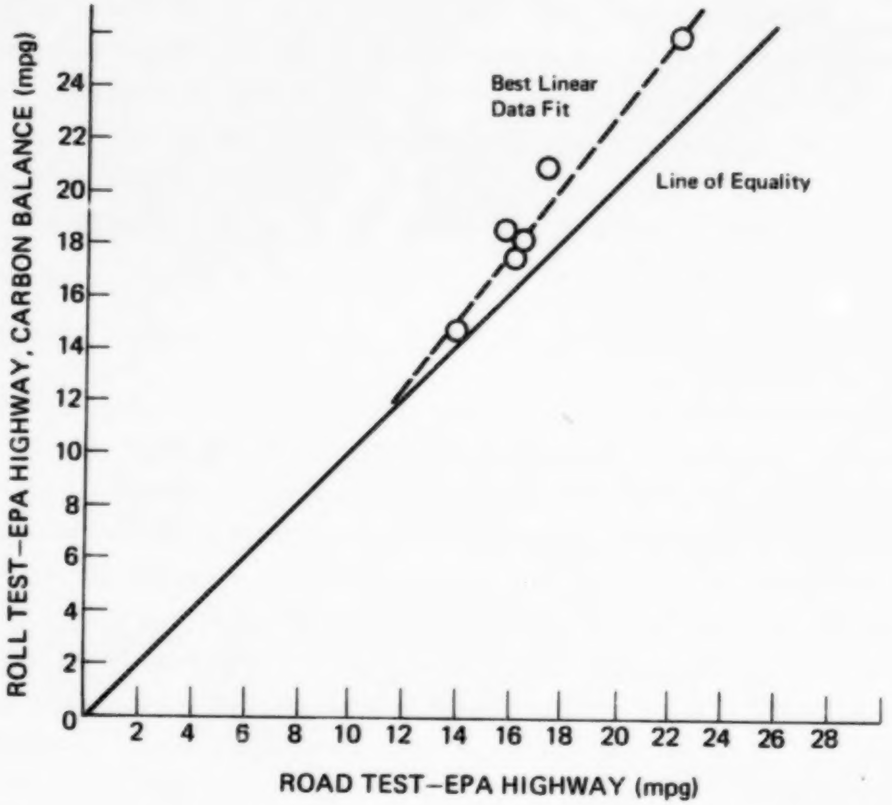

FIGURE 5.8 Fuel Economy for EPA Highway Cycle as Measured on Both a Track and a Dynamometer

REF. 26

idle conditions dominate fuel consumption.[49,53] Therefore, potential errors in dynamometer road-load encountered during CVS-CH tests should not significantly affect the measured fuel economy. Similar computations concerning the energy required to traverse the EPA highway cycle indicate that rolling resistance and aerodynamic drag may constitute as much as 65% to 75% of the energy required. Therefore, errors associated with dynamometer road loads may significantly affect the measured fuel economies on the EPA highway cycle.

5.6 The Affect of Cold-Start and Ambient Temperature on Fuel Economy

As discussed in Section 3.2, many automobile trips are very short, and in the U.S., more vehicle miles are driven for trips within 0.5 miles of 4.5 miles than trips over any other 1-mile interval. In addition, a significant number of vehicle trips are initiated from a cold-start condition which is defined as the initiation of a trip after the vehicle has remained in a stationary position for a period sufficiently long so that it is essentially in thermal equilibrium with local ambient conditions. The severe fuel economy penalties associated with short trips initiated from cold-start are discussed below. In addition, data relating to fuel economy for a specified driving cycle as a function of ambient temperature are presented.

When considering trips of various lengths, it has been proposed that two phases of an urban-cycle fuel economy, cold and warm, must be considered.[46] The cold phase of urban operation includes approximately the first 10 miles of travel and the warm phase is represented by trips longer than 10 miles in duration. During the cold-phase operation, the choke and lubricant warm-up are considered to be major factors in determining fuel economy. The warm phase may be expected to have significant improvements over the cold phase in fuel economy. One method of graphically illustrating the expected fuel economy due to vehicle warm-up versus trip length is shown in Figure 5.9. This figure

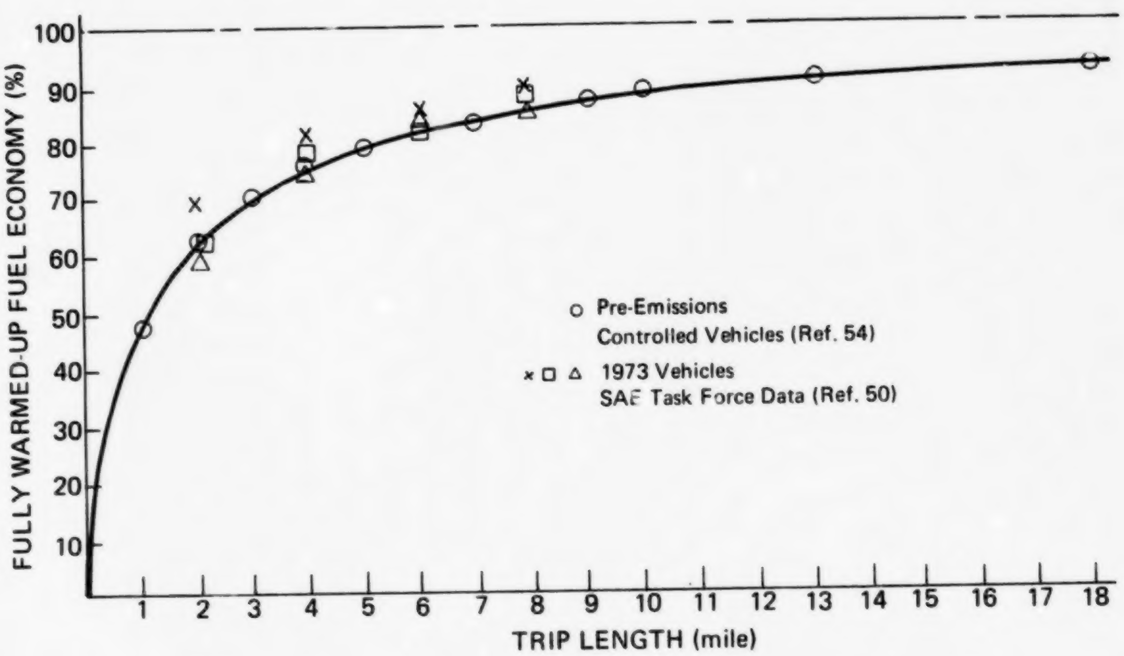

FIGURE 5.9 Effect of Trip Length on Cold-Start Fuel Economy Penalty for an Urban Driving Cycle

indicates that trip length and necessary warm-up have significant effects on fuel economy.

The original data in Figure 5.9, in terms of percent of fully warmed-up fuel economy versus trip lengths, were obtained from Reference 54. These data were obtained for a fleet of pre-emission-control vehicles which were equipped with automatic transmissions and automatic chokes. The vehicles were operated on a simulated city-traffic schedule with a cold start under varying weather conditions. From this graph, it is seen that the average fuel economy for a trip of approximately four miles is only about 75% of the expected fully warmed-up fuel economy. As is seen, the vehicle's average fuel economy approaches the fully warmed-up value only if the trip length is relatively long.

Recently, questions have been raised concerning the validity of these results for vehicles equipped with modern emission controls. In conjunction with the work of the SAE Fuel Economy Task Force, typical cold-start fuel economy data were obtained for a 1974 sports compact and a 1973 intermediate vehicle.[50] Two conditions were studied: one where the vehicle soak temperature was in the range from 25 °F to 45 °F (outdoor soak) and one where the soak range was from 65 °F to 70 °F (indoor soak). The data averaged for a number of urban cycle tests conducted on two vehicles of each type are also plotted in Figure 5.9.

Inspection of these results indicates that vehicles with advanced emission-control systems show the same cold-start fuel economy penalties for various trip lengths as vehicles without emission controls. This result may be due to the fact that the warm-up of many non-emission control related components (e.g., water jacket, transmission, rear end, tires, etc.) may significantly affect cold-start fuel economy.

Since the warm-up effect as discussed is thermal, ambient temperature could also be expected to influence fuel economy. Data reported in Reference 54 indicate that a vehicle will warm up more quickly as the ambient temperature increases. These results indicate that a driver in a cold climate who drives his vehicle for many short trips can expect to receive an average fuel economy for his vehicle which is significantly below that which could be obtained in longer trips and warmer climates. Reference 54 also indicates that a percentage of fully warmed-up fuel economy can be calculated for a highway-type driving cycle. The highway-type warm-up schedule curve reported in Reference 54 falls only slightly above that of the urban or city warmed-up schedule. Note that Figure 5.9 has only been discussed in terms of cold-start conditions. Reference 55 suggests that the trend indicated in Figure 5.9 would also apply to vehicles which are in a warmed-up condition before the trip is started. It would be expected that for a short trip, the average fuel economy of a hot start would be greater than that of the equivalent fuel economy of a cold start for the same driving cycle and trip length.

The influence of ambient temperature on automotive fuel economy is also of interest. The fuel economy of various classes of vehicles on the CVS-CH test cycle as a function of ambient soak and operating temperature as reported by Reference 33 is shown in Figure 5.10. Inspection of these results indicates that a reduction in ambient temperature from 75°F to 20°F results in an average fuel economy penalty of approximately 5% for the twenty 1969 to 1971 model production vehicles and 11% for the prototype catalyst equipped vehicles. Fuel economy penalties of 13% and 9% between 20°F and 75°F were reported for the diesel-equipped and stratified-charge PROCO vehicles, respectively.

Since warm-up is seen to have a significant effect on the average fuel economy of a vehicle and since short trips and cold starts are known to occur with high frequencies as previously discussed, a fuel economy test which includes both a cold and a hot start in an urban cycle would more closely parallel real urban fuel economy. This idea has been incorporated into the CVS-CH test procedure. Note that the hot start of the CVS-CH procedure occurs after a cold start and the first 7.45 miles of the cycle have been driven. Thus, it can be seen

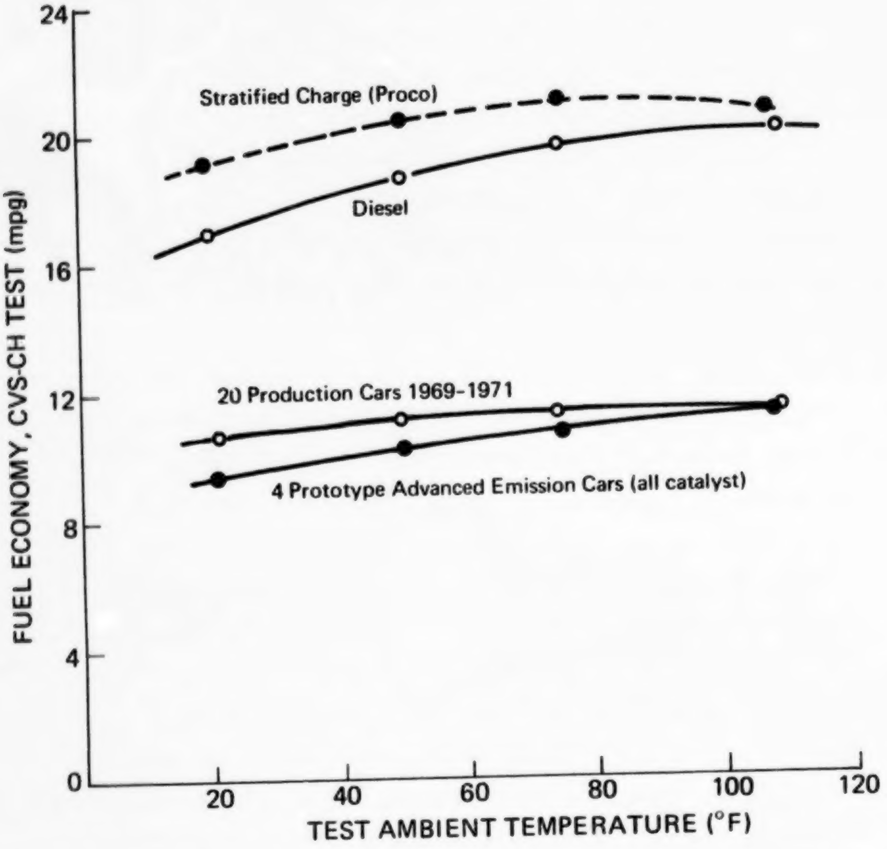

FIGURE 5.10 Effect of Ambient Temperature on Fuel Economy for Various Types of Vehicles on the CVS-CH Test Cycle

REF. 33

by referring to Figure 5.9 that the hot start of the CVS-CH procedure is initiated from a slightly less than fully warmed-up condition.

5.7 Summary

Some of the most important factors that influence the fuel economy of LDMV include the driving cycle and the driving habits of individuals, vehicle characteristics including inertia weight, the effect of cold-start operation, particularly on short trips, and the state of maintenance of the vehicle. It has been suggested that since driving patterns change with time and that two drivers would tend to drive the same route in a different manner, it is impossible to develop an absolutely typical fuel economy driving cycle. However, since fuel economy is strongly dependent on the driving cycle, it is important to develop standardized fuel economy driving cycles and test methods and procedures in order to evaluate the relative fuel economies of various automotive designs and to compare the relative fuel economies of one vehicle versus another. In order to obtain a reasonably accurate determination of the fuel economy of a vehicle, it is concluded that two standard LDMV fuel economy driving cycles, one designed to represent urban driving and one designed to represent highway driving, are needed.

It has been shown that severe fuel economy penalties are incurred when an LDMV is driven on a short trip that is initiated from a cold-start condition. In addition, it has been shown that many automotive trips are very short and that more vehicle miles are driven for trips within 0.5 miles of 4.5 miles than trips over any other 1-mile interval. Therefore, it is concluded that in order to obtain economies that are in good agreement with expected real-life, urban fuel economies, an urban fuel economy test method and procedure should include both a cold-start and hot-start phase. The driving cycle associated with the CVS-CH test method meets this requirement.

The critical elements in any standardized fuel economy test method and procedure include: a representative standard driving cycle or cycles; a method to determine the mass or volume of fuel consumed and the distance traveled during the test; and a procedure for simulating vehicular loads encountered during the course of the driving cycle.

Since the driving cycle associated with the CVS-CH test method meets the criteria for an appropriate urban fuel economy driving cycle and a significant data base of urban fuel economies has been collected with this cycle, it is concluded that the CVS-CH driving cycle can be used as the standard urban fuel economy driving cycle. In addition, it is suggested that either the EPA highway cycle or a combination of the SAE suburban and interstate cycles can be employed as the standard highway fuel economy cycle.

Two methods have been utilized to measure fuel consumption. The first method is based on the direct measurement of mass or volume of fuel consumed during the course of the test. The second method, the Carbon Mass Balance Method, is based on the collection and measurement of carbon containing compounds in the vehicle's exhaust. Since the mass of carbon per gallon of fuel is known, the mass of carbon in the exhaust can be readily employed to compute the mass or volume of fuel consumed during the test. When applying either method, the distance traveled during the test is measured by alternate satisfactory techniques and fuel economy is readily computed. Both of these test methods for fuel consumption measurements have advantages and disadvantages and are subject to significant errors if careful experimental techniques and procedures are not followed. However, under conditions where both techniques can be simultaneously employed, either method can be used to obtain accurate measurements of fuel consumption.

Two procedures have been proposed for simulating vehicular loads encountered during the course of the driving cycle. One method is based on driving the vehicle over a suitable road or test track, and the second method is based on driving the vehicle on a chassis dynamometer. Both of these procedures have distinct advantages and disadvantages. It has been concluded that there is no inherent technical reason for eliminating the use of chassis dynamometers from fuel economy testing if it can be shown that they adequately simulate the actual inertial, aerodynamic, rolling resistance and accessory loads experienced by a vehicle as it traverses the driving cycle. Unfortunately, the results of definitive studies designed to evaluate the ability of chassis dynamometers to accurately simulate vehicle loads under a wide variety of conditions and to evaluate errors in fuel economy measurements associated with specified errors in dynamometer load simulation have not been reported.

Based on the limited data presently available, one can speculate that fuel economy tests incorporating chassis dynamometers, with suitably fine inertia-weight controls, can be successfully employed to determine fuel economies for urban driving cycles where inertia forces and idle conditions rather than road loads dominate LDMV fuel consumption. In addition, limited data have indicated that fuel economy data obtained on chassis dynamometers and road or track tests can be made to correlate well even for nonurban driving cycles, where road loads dominate vehicle fuel consumption, if care is taken to set the dynamometer loading so that vehicle coast-down times obtained on the dynamometer closely match vehicle coast-down times obtained on the road. The results of another study indicate that fuel economies for the EPA highway driving cycle as measured on a Clayton-type dyno, where the road load at 50 mph was set according to the "cook book" method established in the Federal Register, did not correlate well with results obtained on a test track. In all cases, the fuel economies measured on the dyno were larger than the corresponding values measured on the track and differences between the two values ranged from 4% to 16%. These results indicate that certain vehicles may obtain significantly higher fuel economies than are actually warranted on the EPA highway cycle using present EPA fuel economy test methods and procedures.

Fuel economy measurements are considerably more reproducible than emissions measurements. Data obtained during the course of this study indicate that fuel economy measurements employing chassis dynamometers for an urban driving cycle (e.g., CVS-H, CVS-C and CVS-CH tests) are reasonably repeatable. In fact, the data indicate that the variability of measured fuel economy in terms of the standard deviation as a percent of the mean in a given cell, from cell to cell at a given laboratory and from laboratory to laboratory, is in the range of 2% to 8%. The limited data obtained for reproducibility studies on the EPA highway cycle have indicated a similar variability.

It has been reported that a large number of fuel economy measurements carried out on test tracks have indicated that vehicle-to-vehicle variation in fuel economy for identical vehicles is of the order of 3.5% of the mean fuel economy. The results of a study designed to determine the variability of results from both test-track and chassis-dynamometer fuel economy tests have also been reported. The study concluded that with a single vehicle the true population mean can be established within approximately 7% for a city/suburban driving cycle on a test track and approximately 11% for the urban CVS-C test cycle on a chassis dynamometer with 90% confidence. The sample sizes required to predict mean fuel economy for a given car line within 3% of the true population mean at 90% confidence were estimated to require testing of 5 vehicles for the test-track cycle compared to 14 vehicles for the laboratory chassis-dynamometer cycle.

Due to the potential significance that may be attached to reported fuel economies of individual vehicles, it is suggested that reported fuel economies be based on the results of several tests.

6.0 EVALUATION OF THE DATA

6.1 Summary

The important aspects of present and projected emission and fuel economy test methods and procedures for LDMV have been considered. The CVS-CH exhaust emission test procedure plays an important role in the certification process for 1975 and subsequent model-year LDMV. Hence, the statistical variability of CVS-CH exhaust emission tests for these vehicles and the relative magnitudes of the various factors affecting both systematic and random errors encountered during CVS-CH tests were discussed. Additional questions concerning the effect of ambient temperature on exhaust emissions, the suitability of present exhaust emission-control durability test methods and procedures and the possible modifications of the present HC exhaust-emission standards and measuring techniques designed to account for only reactive HC were also addressed. Finally, recent data relating to the effectiveness of present evaporative HC emission-test methods and procedures and LDMV evaporative-control systems were presented and discussed.

At the present time, generally accepted standardized fuel economy test methods and procedures are not available. Due to the significance of this issue, it is important that standardized test methods and procedures, based on sound engineering and scientific considerations, be developed as soon as possible. In the general area of fuel economy, the important factors affecting LDMV fuel economy, the important elements in any standardized fuel economy test method and procedure, the currently proposed test methods and procedures and the statistical variability of fuel economy measurements were considered in some detail.

6.2 Conclusions

The major conclusions reached during this study have been summarized in Section 1.2. A more detailed summary of the major conclusions and the supporting data are given below:

1. Recent data, obtained utilizing the SHED method, indicate that evaporative HC emissions from vehicles equipped with present-technology, evaporative-control systems are of the order of 1.9 g/mi which is larger than the 1975-76 federal HC exhaust emission standards of 1.5 g/mi. These results were obtained on systems in which evaporative HC emissions were reportedly 95% controlled with respect to uncontrolled HC evaporative emission levels of approximately 3.0 g/mi. Therefore, an accurate test method and procedure for measuring evaporative HC emissions must be developed and implemented as soon as possible. Careful evaluation of the situation may show that the SHED method is adequate for this purpose.
2. The driving cycle associated with the CVS-CH test was found to represent an average urban trip "as well as it needs to" for purposes of determining LDMV exhaust emissions.
3. Significant consequences should not be attached to a single CVS-CH exhaust-emissions test since both random and systematic errors contribute to poor repeatability of exhaust-emission test results for a given LDMV. Various factors, including vehicle variability, emission collection and measurement variability and environmental test variables, contribute to the poor test reproducibility. Variations in exhaust-emission measurements specified in terms of the standard deviation as a percent of the mean for a 1975-76 vehicle in a given cell or from cell to cell at one laboratory for most engine-control system configurations can be expected to range between 10% to 25%, 15% to 30% and 5% to 15% for HC, CO and NO_x, respectively.
4. Significant systematic errors in mean emission values of a given test vehicle of as much as 20% to 30% have been reported between various emission-testing laboratories. Establishment of mandatory correlation test programs among governmental, automotive manufacturers' and other test laboratories that are

carrying out exhaust emission measurements on the CVS-CH test could significantly reduce these errors. These correlation programs should include CVS-CH tests of relatively stable vehicles and tests of the CVS sampling and gas analysis systems using either exhaust-gas generators or premixed-gas cylinders as the gas source. Once systematic measurement errors are isolated at a given facility, they can be corrected or the measurements can be adjusted to take them into account.

5. Fluctuations in test-cell temperature and humidity, within the ranges specified in the CVS-CH test method, and variations in barometric pressure have been shown to significantly affect measured exhaust emissions. Presently, no controls are placed on humidity and ambient temperature is allowed to vary between 68 °F and 86 °F during CVS-CH tests. Modification of the CVS-CH test procedure incorporating close control of both ambient temperature and humidity would decrease the statistical variation in exhaust-emission measurements. Unfortunately, barometric pressure cannot be conveniently controlled during the course of CVS-CH tests. Since both systematic and random variations of barometric pressure occur between test laboratories, appropriate correction factors relating variations in barometric pressure to exhaust emissions should be applied to CVS-CH tests.
6. Ambient temperature variations, commonly encountered in large sections of the nation during winter (e.g., 0 °F-32 °F), can significantly increase exhaust emissions of HC and CO, for both pre-1975 production vehicles and 1975 prototype models equipped with oxidation catalysts, above the emissions measured during the course of the CVS-CH test. As an example of this effect, the HC and CO emissions from four prototype catalyst-equipped vehicles were shown to increase by 160% and and 409%, respectively, when the vehicles were tested at 20 °F

in comparison to 75 °F. The NO_x emissions for these same vehicles increased by approximately 33% over the same temperature interval.

7. Statistical variability associated with the evaluation of deterioration factors, often obtained from tests on a single durability-data car, may reflect the special circumstances of the test rather than the capability of the underlying technology. An averaging procedure over a larger group of similar vehicles might be preferable. However, averaging, if used too extensively, treats all vehicles and systems as equal, and attractive technologies are counterbalanced by less desirable technologies.
8. The critical elements in any standardized fuel economy test method and procedure include: a representative standard driving cycle or cycles; a method to determine the mass or volume of fuel consumed and the distance traveled during the test; and a procedure for simulating vehicular loads encountered during the course of the driving cycle.
9. Significant vehicular miles are driven in both urban and nonurban environments and fuel economy in these two driving modes may differ by approximately 50%. Two fuel economies, one designed to represent urban driving and one designed to represent highway driving, will provide the required basis for evaluating the relative fuel economies of various automotive designs and comparing the relative fuel economies of one vehicle versus another.
10. It has been shown that severe fuel economy penalties are incurred when an LDMV is driven on a short trip that is initiated from a cold-start condition. Since a significant number of urban trips are very short and initiated from a cold start, an urban fuel economy driving cycle should include a cold-start phase.

11. The CVS-CH driving cycle is a sufficiently accurate representation of urban driving patterns to be used as the urban fuel economy driving cycle.
12. A fuel economy driving cycle similar to the EPA highway cycle or a combination of the SAE suburban and interstate cycles may be appropriate for measurements of highway driving fuel economies.
13. Either the Carbon Mass Balance Method or the direct measurement of the mass or volume of fuel consumed can be employed to obtain accurate measurements of fuel consumption if careful experimental techniques and procedures are developed and followed. Both of these test methods for fuel-consumption measurements have disadvantages and advantages and are subject to significant errors if careful experimental techniques and procedures are not followed.
14. Two procedures have been proposed for simulating vehicular loads encountered during the course of the driving cycle. One method is based on driving the vehicle over a suitable road or test track, and the second method is based on driving the cycle on a chassis dynamometer. Both of these procedures have distinct advantages and disadvantages.
15. There is no inherent technical reason for eliminating the use of chassis dynamometers from fuel economy testing if it can be shown that they adequately simulate the actual inertial, aerodynamic, rolling resistance and accessory loads experienced by a vehicle as it traverses the driving cycle. Unfortunately, the results of definitive studies designed to evaluate the ability of chassis dynamometers to accurately simulate vehicle loads under a wide variety of conditions and to evaluate any errors in fuel economy measurements associated with specified errors in dynamometer load simulation have not been reported.

16. Limited data presently available indicate that fuel economy tests incorporating chassis dynamometers, with suitably fine inertia-weight controls, can be successfully employed to determine fuel economies for urban driving cycles where inertia forces and idle conditions, rather than road loads, dominate LDMV fuel consumption.
17. Limited data have indicated that fuel economy data obtained on chassis dynamometers and road or track tests can be made to correlate well even for nonurban driving cycles, where road loads dominate vehicle fuel consumption, if care is taken to set the dynamometer loading so that vehicle coast-down times obtained on the dynamometer closely match vehicle coast-down times obtained on the road. However, the results of another study indicate that fuel economies for the EPA highway driving cycle as measured on a Clayton-type dyno, where the road load at 50 mph was set according to the "cook book" method established in the Federal Register, did not correlate well with results obtained on a test track. In all cases, the fuel economies measured on the dyno were larger than the corresponding values measured on the track and differences between the two values ranged from 4% to 16%. These results indicate that certain vehicles may obtain significantly higher fuel economies than are actually warranted on the EPA highway cycle using present EPA fuel economy test methods and procedures.
18. Fuel economy measurements are considerably more reproducible than emission measurements. Data indicate that fuel economy measurements employing chassis dynamometers for an urban driving cycle (e.g., CVS-H, CVS-C, and CVS-CH tests) are reasonably repeatable. In fact, the data indicate that the variability of measured fuel economy in terms of the standard deviation as a percent of the mean in a given cell, from cell to cell at a given laboratory and from laboratory to laboratory

is in the range of 2% to 8%. The limited data obtained for reproducibility studies on the EPA highway cycle have indicated a similar variability. However, due to the potential significance that may be attached to reported fuel economies of individual vehicles, reported fuel economies should be based on the results of several tests.

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APPENDIX A

Organizations Site-Visited or Interviewed

1.	Environmental Protection Agency Emission Control Technology Division Ann Arbor, Michigan	January 23, 1974
2.	Fuel Economy Measurement Procedures Task Force Society of Automotive Engineers Romulus, Michigan	February 6, 1974
3.	Environmental and Safety Relations Chrysler Corporation Detroit, Michigan	February 12, 1974
4.	World Headquarters Ford Motor Company Dearborn, Michigan	February 13, 1974
5.	Environmental Activities Staff General Motors Corporation Warren, Michigan	February 14, 1974
6.	Transportation Systems Center Department of Transportation Cambridge, Massachusetts	March 1, 1974
7.	Volkswagen of America, Inc. (meeting in Washington, D.C.)	March 5, 1974
8.	Environmental Protection Agency Emission Control Technology Division and Surveillance Branch Ann Arbor, Michigan	April 3, 1974
9.	Mobil Research and Development Corporation Paulsboro, New Jersey	May 8, 1974
10.	California Air Resources Board El Monte, California	May 13, 1974
11.	Clayton Manufacturing Company El Monte, California	May 13, 1974
12.	Automotive Power Systems Evaluation Study Jet Propulsion Laboratory Pasadena, California	May 13, 1974

13.	Olsen Laboratories, Inc. Anaheim, California	May 14, 1974
14.	Emission Development American Motors Detroit, Michigan	June 5, 1974
15.	Vehicle Emissions Planning Chrysler Corporation Detroit, Michigan	June 5, 1974
16.	World Headquarters Ford Motor Company Dearborn, Michigan	June 6, 1974
17.	Proving Ground General Motors Corporation Melford, Michigan	June 7, 1974
18.	Bartlesville Energy Research Center Bureau of Mines Bartlesville, Oklahoma (Interview in Denver, Colorado)	June 11, 1974
19.	Department of the Environment London, England	June 17, 1974
20.	Ministere de l'Amenagement du Territoire Paris, France	June 18, 1974
21.	Vereinigung Deutscher Automobilhersteller Frankfurt, West Germany (Interview in Geneva, Switzerland)	June 19, 1974
22.	Advance Engineering Department Saab-Scania Aktiebolag Trollhattan, Sweden	June 24, 1974
23.	Ministero dei Transporti e dell Aviazione Civile Roma, Italia	June 25, 1974
24.	Environmental Activities Staff General Motors Corporation Warren, Michigan (Interview in Philadelphia, Pennsylvania)	September 5, 1974

25. Additional information was obtained from the following Foreign Manufacturers' presentations to CMVE meeting in Washington, DC, May 21-24, 1974:

    a. Daimler-Benz AG
    b. Fiat, S.p.A./Ferrari
    c. Honda Motor Company
    d. Nissan Motor Company, Ltd.
    e. Adam Opel AG
    f. Peugeot, Inc.
    g. Regie Nationale des Usines Renault
    h. Saab-Scania Aktiebolag
    i. Toyo Kogyo Company, Ltd.
    j. Toyoto Motor Company, Ltd.
    k. Volkswagenwerk AG
    l. AB Volvo

APPENDIX B

General Questions to Organizations Prior to Site Visit
from the Consultant on Testing
of the
Committee on Motor Vehicle Emissions

A. Test Cycles

1. Discussion of the advantages and disadvantages of the application of the 1975 FTP as a basis for emissions standards testing and for the determination of urban fuel economy.

2. Summary of any studies that have been carried out to evaluate typical driving patterns in urban, nonmetropolitan and rural areas. Items of particular interest include distribution of number of trips versus trip length, percentage of trips initiated from "cold start" versus "hot start," average trip speed, number of stops per mile, etc.

3. Constructive evaluation of EPA's recently proposed nonmetropolitan fuel economy driving cycle.

B. Test Methods and Procedures

1. Emissions

    a. Discussion of any special shortcomings or problems associated with present emissions test procedures, special emphasis should be given to CVS sampling system, instrumental limitations for pollutant measurements, etc.

    b. Discussion of relative advantages and disadvantages of modifying HC standards to incorporate only a non-methane hydrocarbon standard.

    c. Summary of work to date on development of test methods and procedures developed to measure H_2S, SO_x and sulfates in automotive exhaust.

    d. Discussion of the accuracy of present gas calibration standards used in emission testing and its effect on accuracy of emission measurements.

    e. Discussion of the contribution of various factors to the statistical variability of emission tests.

2. Fuel Economy

    a. Discussion of Carbon Mass Balance Methods versus Weighing Methods to determine fuel economy.

    b. Discussion of chassis dynamometer versus road/track test procedures for the determination of fuel economies.

    c. Critical evaluation of the use of chassis dynamometer facilities to simulate road loads for fuel economy tests. Items of particular interest include the dynamometer's ability to accurately simulate rolling resistance and aerodynamic drag. In addition, problems associated with the effect of cooling fan characteristics on vehicle warm-up, etc. should be discussed.

    d. Discussion of the contribution of various factors to the statistical variability of fuel economy tests.

    e. Discussion of the relative importance of rolling resistance and aerodynamic drag as they apply to vehicle road load as a function of vehicle speed.

3. Vehicle Driveability

    a. Discussion of qualitative test methods to determine vehicle driveability.

    b. Discussion of quantitative test methods to determine vehicle driveability.

C. Experimental Results

1. Emissions

    a. Data on any inner-lab and intra-lab reproducibility and/or correlation testing programs on vehicular emissions.

    b. Data on statistical variability of emissions from a single vehicle undergoing many tests and/or from a group of similar production model vehicles.

    c. Data detailing the effect of ambient conditions (special consideration to temperature) on emissions.

    d. Data summarizing H_2S, SO_x and sulfate emissions from catalyst equipped vehicles.[2]

e. Data on HC evaporative emissions as obtained in SHED tests. Comparison of total HC evaporative emissions as obtained in SHED tests versus "cannister" tests.

2. Fuel Economy

   a. Data on any inner-lab and intra-lab reproducibility and/or correlation testing programs on vehicular fuel economy.

   b. Data on statistical variability of fuel economy from a single vehicle undergoing many tests and/or from a group of similar production model vehicles.

   c. Data detailing the effect of ambient conditions (special consideration to temperature) on fuel economy.

   d. Data on fuel economy versus trip length and any data relating to the relative fuel economies of a specified trip when the trip is initiated from a "cold start" versus a "hot start."

   e. Data on fuel economy penalties associated with vehicle accessories, transmission type, etc.

3. General Considerations

   a. Data on road load on vehicles versus vehicle speed.

      i. Rolling resistance versus speed
      ii. Aerodynamic drag versus speed

   b. Data on relative importance of inertia forces and road load as a function of vehicle speed and acceleration.

GLOSSARY

A/F	air/fuel
AMA	Automobile Manufacturers Association
AMC	American Motors Corporation
ASIA	Automotive Service Industry Association
AT	automatic transmission
CCS	direct-fuel-injected, stratified-charge engine such as the Ford PROCO or Texaco TCCS
CID	cubic inch displacement
CMVE	Committee on Motor Vehicle Emissions
CNG	compressed natural gas
CR	compression (or expansion) ratio
CVCC	prechamber, dual-carburetor stratified-charge engine such as the Honda Motor Company Compound Vortex-Controlled Combustion Engine
CVS	constant volume sample emissions test procedure
CVS-CH	constant volume sample--cold and hot start emissions test procedure
Cyl	cylinder
DF	deterioration factor
Dual Cat	a reducing catalyst followed by an oxidizing catalyst
EFI	electronic fuel injection
EGR	exhaust gas recirculation
EPA	U.S. Environmental Protection Agency
FI	fuel injection
FTP	Federal Test Procedure
GM	General Motors Corporation
g/mi	grams/mile of emissions
GT	gas turbine
HC	various hydrocarbon compounds
HCAT	oxidizing catalyst system for removal of HC and CO
ICE	internal combustion engine
IFC	integrated fuel control (carburetor)
JPL	Jet Propulsion Laboratory, California Institute of Technology

LBS.........	lean-burn engine system
LDMV........	light-duty motor vehicle
LPG.........	liquefied petroleum gas
M/C.........	Manufacturing and Costs Panel of CMVE
Modif.......	standard internal-combustion engine modified with emissions controls such as spark retard and air pump
MON.........	motor octane number
mpg.........	miles per gallon fuel economy
MT..........	manual transmission
MVMA........	Motor Vehicles Manufacturers Association
NIASE.......	National Institute for Automotive Service Excellence
NO_x.........	various nitrogen oxide compounds
P...........	production
PCV.........	positive crankcase ventilation
pp..........	pre-production
PROCO.......	Ford--Programmed Combustion Process (direct-fuel-injected, spark-ignited, open-chamber, stratified-charge engine)
R...........	research
RE..........	rotary engine
RON.........	research octane number
SAE.........	Society of Automotive Engineers
SHED........	sealed housing for evaporative (emissions) determinations
std. dev....	standard deviation
TCCS........	Texaco controlled combustion system (direct-fuel-injected, spark-ignited, open-chamber, stratified-charge engine)
3-way cat...	combined oxidizing and reducing catalyst
UDDS........	urban dynamometer driving cycle
VMT.........	vehicle miles traveled